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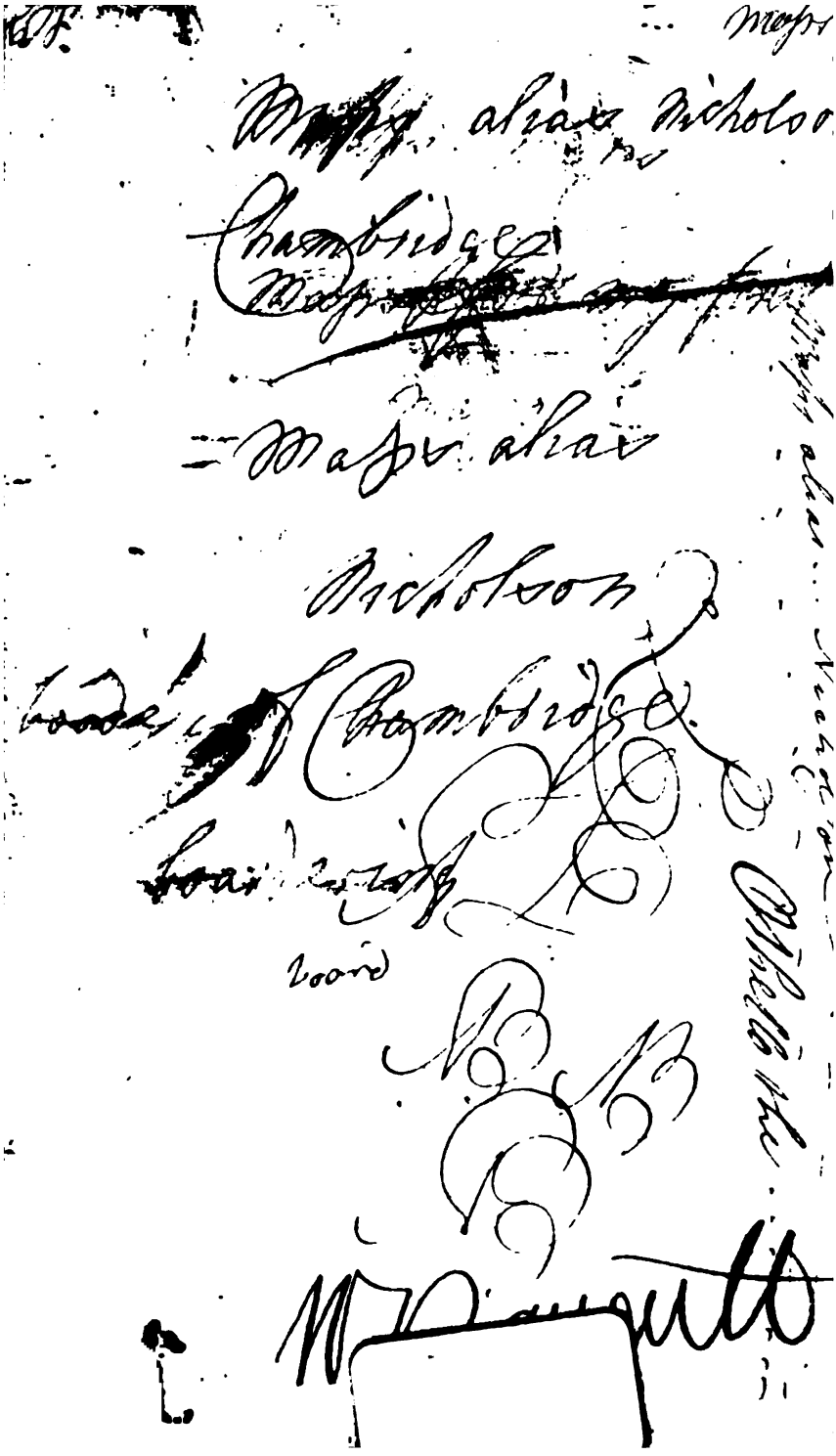
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# A TREATISE OF ALGEBRA, IN THREE PARTS.

CONTAINING

I. The fundamental Rules and Operations.

II. The Composition and Resolution of Equations of all Degrees; and the different Affections of their Roots.

III. The Application of Algebra and Geometry to each other.

To which is added an

## APPENDIX,

Concerning the general Properties of Geometrical Lines.

By COLIN MACLAURIN, M. A.

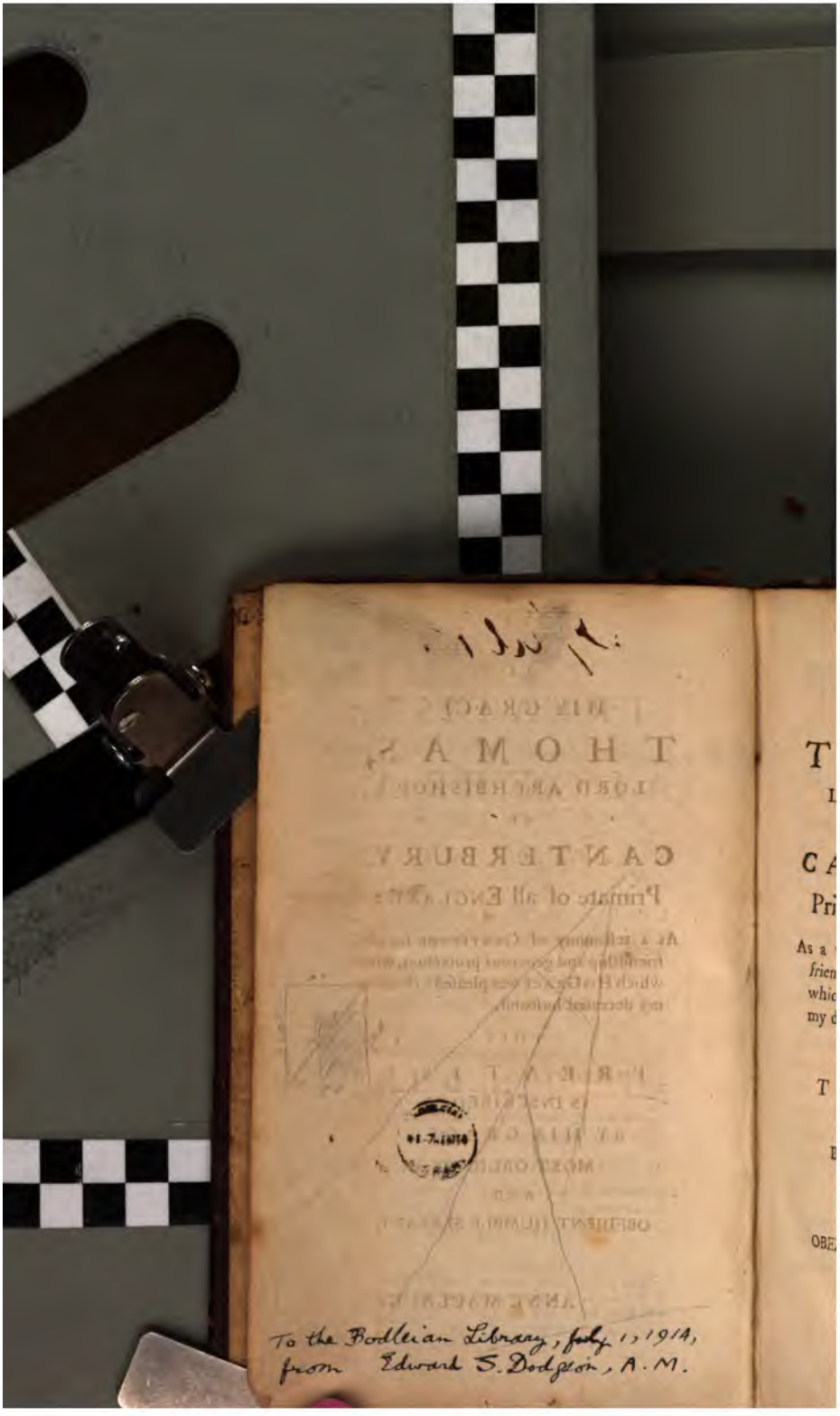
Late Professor of Mathematicks in the University of Edinburgh, and Fellow of the Royal Society.

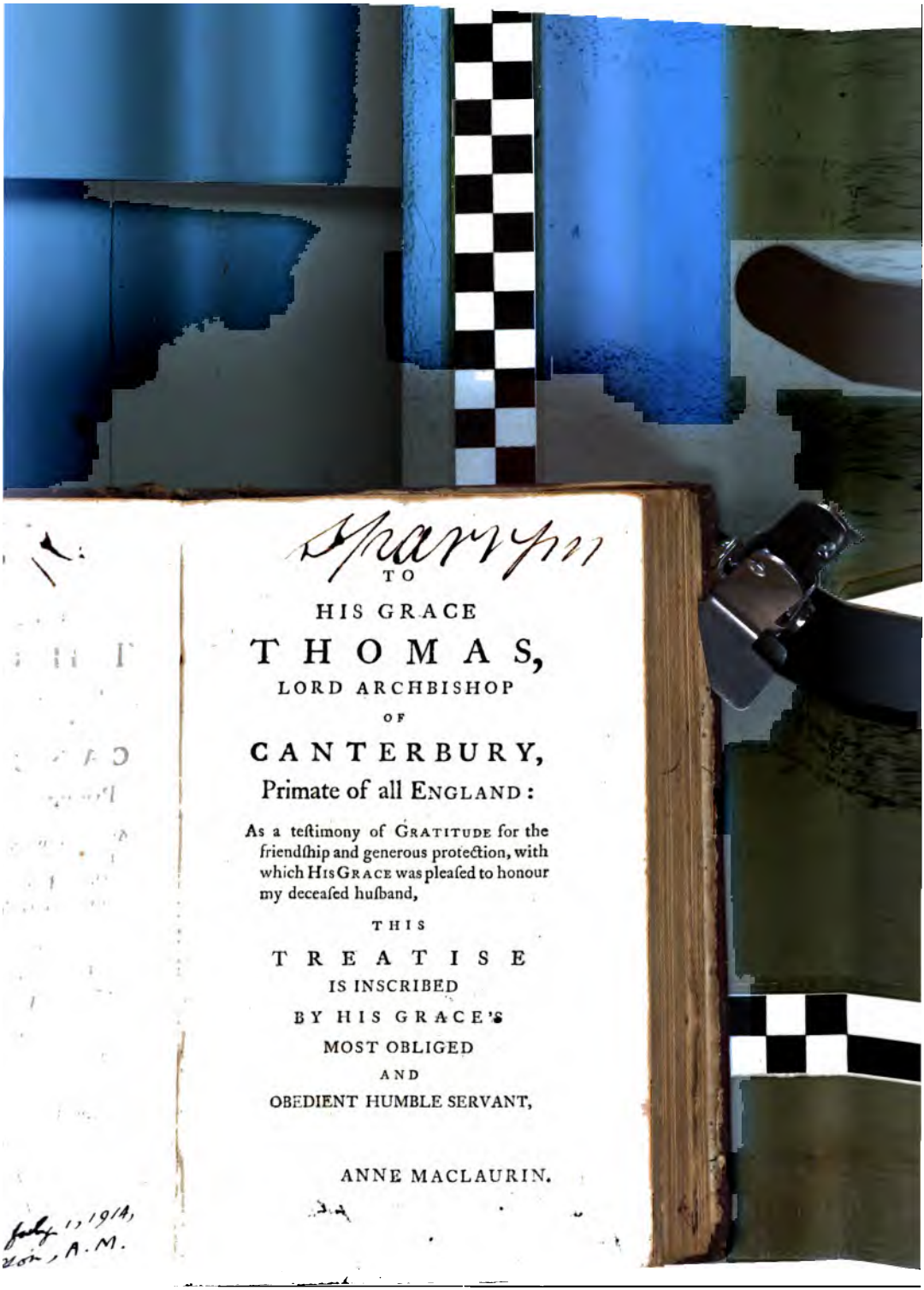
The THIRD EDITION.

LONDON,

Printed for J. Nourse, W. Strahan, J. and F. Rivington, W. Johnston, T. Longman, Robinson and Roberts, S. Bladon, and T. Cadell. 1775.

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To the Bodleian Library, July 1, 1914,
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TO

HIS GRACE

THOMAS,

LORD ARCHBISHOP

OF

CANTERBURY,

Primate of all ENGLAND:

As a teſtimony of GRATITUDE for the friendſhip and generous protection, with which HIS GRACE was pleaſed to honour my deceaſed huſband,

THIS

TREATISE

IS INSCRIBED

BY HIS GRACE'S

MOST OBLIGED

AND

OBEDIENT HUMBLE SERVANT,

ANNE MACLAURIN.

TO THE

# READER.

TO THE

# READER.

THAT Mr. MACLAURIN *had, many years ago, intended to publiſh a Treatiſe on this ſubject, appears from a letter, dated April* 19, 1729, *to his honoured friend* MARTIN FOLKES, *Eſq; now Preſident of the Royal Society*. And we find, in one of his manuſcripts, the Plan of ſuch a Work, agreeing, almoſt in every article, with the contents of this Volume.*

*Had the celebrated Author lived to publiſh his own Work, his name would, alone, have been ſufficient to recommend it to the notice of the Publick: but that Taſk having, by his lamented premature death, devolved to the gentlemen whom he left entruſted with his Papers, the Reader may reaſonably expect ſome account of the materials of which it conſiſts, and of the care that has been taken in collecting and diſpoſing them, ſo as beſt to anſwer the Author's intention, and fill up the Plan he had deſigned.*

* Phil. Tranſ. N° 408.

*He seems, in compoſing this Treatiſe, to have had theſe three Objects in view.*

1, *To give the general* Principles *and* Rules *of the Science, in the ſhorteſt, and, at the ſame time, the moſt clear and comprehenſive manner that was poſſible. Agreeable to this, though every Rule is properly exemplified, yet he does not launch out into what we may call, a* Tautology *of examples. He rejects ſome applications of* Algebra, *that are commonly to be met with in other writers; becauſe the number of ſuch applications is endleſs: and, however uſeful they may be in Practice, they cannot, by the rules of good* method, *have place in an* elementary *Treatiſe. He has likewiſe omitted the Algebraical ſolution of* particular *Geometrical problems, as requiring the knowledge of the Elements of* Geometry; *from which thoſe of* Algebra *ought to be kept, as they really are, entirely diſtinct; reſerving to himſelf to treat of the mutual relation of the two Sciences in his* Third Part, *and, more generally ſtill, in the* Appendix. *He might think too, that ſuch an application was the leſs neceſſary, that* Sir ISAAC NEWTON's *excellent Collection of Examples is in every body's hands, and that there are few Mathematical writers,*

*who*

*who do not furniſh numbers of the ſame kind.*

2. *Sir* ISAAC NEWTON's *Rules, in his* Arithmetica Univerſalis, *concerning the Reſolution of the higher equations, and the Affections of their roots, being, for the moſt part, delivered without any demonſtration, Mr.* MACLAURIN *had deſigned, that his Treatiſe ſhould ſerve as a Commentary on that Work. For we here find all thoſe difficult paſſages in Sir* ISAAC's *Book, which have ſo long perplexed the Students of Algebra, clearly explained and demonſtrated. How much ſuch a Commentary was wanted, we may learn from the words of a late eminent Author*.*

"The ableſt Mathematicians of the laſt age "*(ſays he)* did not diſdain to write Notes on "the Geometry of DES CARTES; and ſure"ly Sir ISAAC NEWTON's Arithmetick no "leſs deſerves that honour. To excite ſome "one of the many ſkilful Hands that our "times afford to undertake this Work, and "to ſhew the Neceſſity of it, I give this "*Specimen*, in an explication of two paſ-"ſages

* s'*Graveſande* in Præfat. ad Specimen Comment. in Arith. Univerſ.

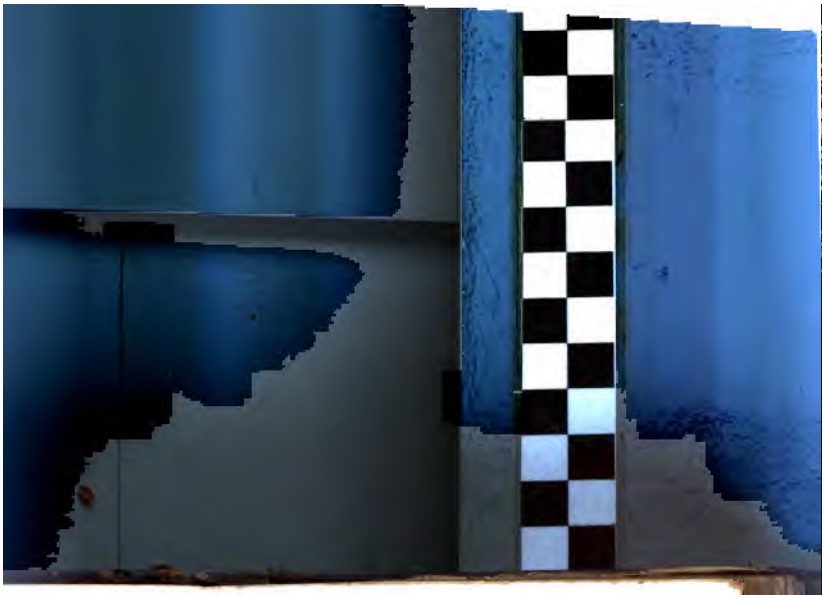
"sages * of the *Arithmetica Universalis*; "which, however, are not the most diffi-"cult in that Book."

*What this learned Professor so earnestly wished for, we at last see executed; not separately, nor in the loose disagreeable form which such Commentaries generally take, but in a manner equally natural and convenient; every Demonstration being aptly inserted into the Body of the Work, as a necessary and inseparable Member; an Advantage which, with some others, obvious enough to an attentive Reader, will, it is hoped, distinguish this Performance from every other, of the kind, that has hitherto appeared.*

3. *After having fully explained the Nature of Equations, and the Methods of finding their Roots, either infinite expressions, when it can be done, or in infinite* converging series; *it remained only to consider the Relation of* Equations *involving two variable quantities, and of Geometrical* Lines *to each other; the Doctrine of the* Loci; *and the* Construction *of Equations. These make the Subject of the* Third Part.

* *Viz.* The finding of *Divisors*, and the evolution of *Binomial Surds*. See § 59—72. Part II. § 127. Part I.

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## To the READER.

*Upon this Plan Mr.* MACLAURIN *compoſed a ſyſtem of* Algebra, *ſoon after his being choſen Profeſſor of Mathematicks in the Univerſity of* Edinburgh; *which he, thenceforth, made uſe of in his ordinary Courſe of Lectures, and was occaſionally improving to the Perfection he intended it ſhould have, before he committed it to the Preſs. And the beſt Copies of his Manuſcript having been tranſmitted to the Publiſher, it was eaſy, by comparing them, to eſtabliſh a correct and genuine Text. There were, beſides, ſeveral detached Papers, ſome of which were quite finiſhed, and wanted only to be inſerted in their proper places. In a few others, the Demonſtrations were ſo conciſely expreſſed, and couched in Algebraical characters, that it was neceſſary to write them out at more length, to make them of a piece with the reſt. And this is the only liberty the Publiſher has allowed himſelf to take; excepting a few inconſiderable additions, that ſeemed neceſſary to render the Book more compleat within itſelf, and to ſave the trouble of conſulting others who have written on the ſame Subject.*

*The Rules concerning the* Impoſſible roots *of Equations, our Author had very fully conſidered, as appears from his Manuſcript papers: but as he had no where reduced any thing on*

*that*

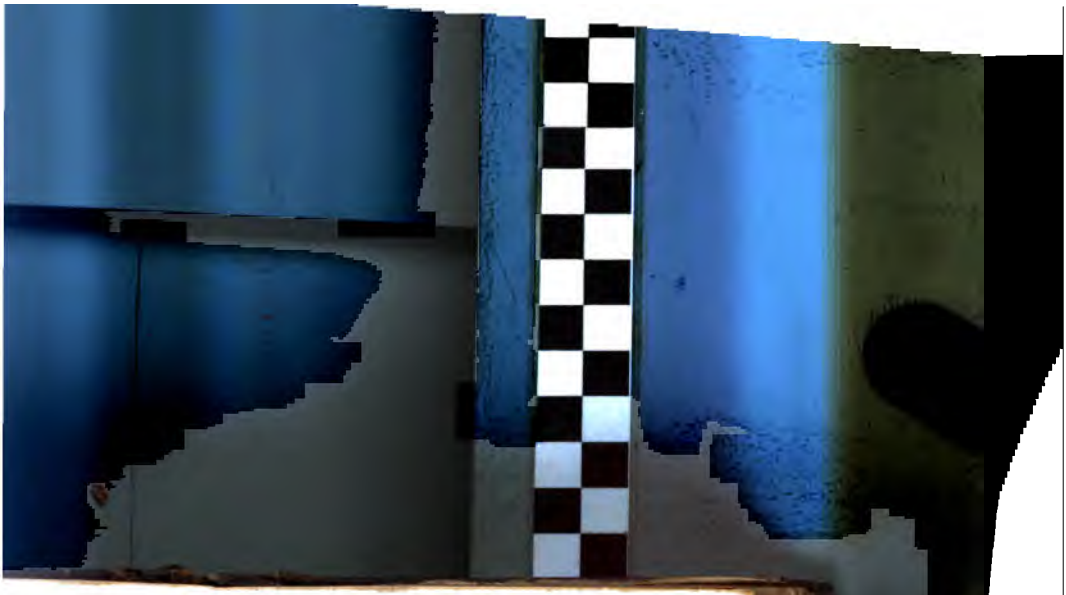
*that Subject to a better form, than what was long ago published in the* Philosophical Transactions, N° 394, *and* 408. *we thought it best to take the substance of* Chap. 11. Part II. *from thence; especially as the latter of these Papers furnishes a demonstration of the original Rule, which pre-supposes only what the Reader has been taught in a preceding Chapter.*

*The Paper that is subjoined, on the* Sums of the Powers of the Roots of an Equation, *is taken from a Letter of the Author* (8 Jul. 1743) *to the Right Honourable the Earl* STANHOPE; *communicated to the Publisher, with some things added by his Lordship, which were wanting to finish the Demonstration.*

*Of these Materials, carefully collected and put in order, the following* Elementary Treatise *is composed; which we have chosen rather to give in a Volume that is within the reach of every Student, than in one more pompous, which might be less generally useful. And we hope, from the pains it has cost us, its blemishes are not many, nor such as a candid intelligent Reader may not forgive.*

*The* Latin Appendix *is a proper Sequel, and a high Improvement, of what had been demonstrated in* Part. III. *concerning the Relation of* Curve lines *and* Equations; *a Subject which*

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*our Author had been early and intimately acquainted with; witneſs his* Geometria Organica, *printed in* 1719, *when he was not full twenty-one years of age, and which, though ſo juvenile a work, gained him, at once, that diſtinguiſhed Rank among Mathematicians, which he thenceforth held with great luſtre. Yet he frankly owns, he was led to many of the Propoſitions in this* Appendix, *from a Theorem of Mr.* COTES, *communicated to him, without any demonſtration, by the Reverend and Learned Dr.* SMITH, *Maſter of* Trinity-College, Cambridge. *How he has profited of that Hint, the Learned will judge: Thus much we can venture to ſay, that he himſelf ſet ſome value upon this Performance; having, we are told, employed ſome of the lateſt hours he could give to ſuch Studies, in reviſing it for the Preſs; to bequeath it as his laſt Legacy to the Sciences and to the Publick.*

*The gentlemen to whom Mr.* MACLAURIN *left the care of his Papers, are* MARTIN FOLKES, *Eſq; Preſident of the Royal Society;* ANDREW MITCHEL, *Eſq; and the Reverend Mr.* HILL, *Chaplain to his Grace the Archbiſhop of* Canterbury; *with whom he had lived in a moſt intimate friendſhip. And by their direction this Treatiſe is publiſhed.*

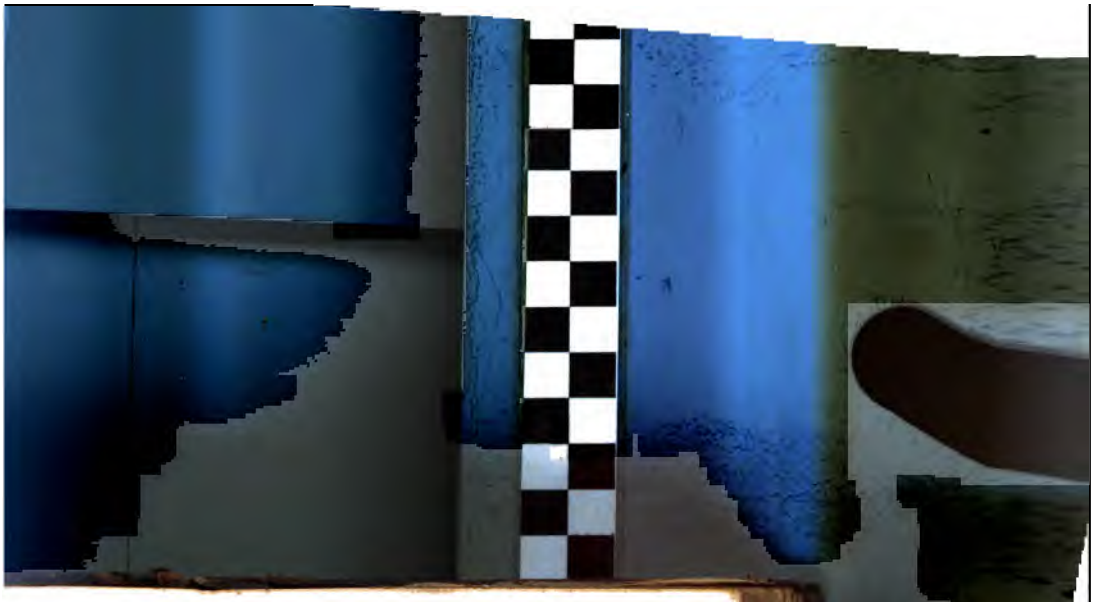
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# TREATISE

OF

# ALGEBRA.

## PART I.

### CHAP. I.

*Definitions and Illustrations.*

§ 1. ALGEBRA is a general method of computation by certain signs and symbols which have been contrived for this purpose, and found convenient. It is called an UNIVERSAL ARITHMETICK, and proceeds by operations and rules similar to those in common arithmetick, founded upon the same principles. This, however, is no argument against its usefulness or evidence; since arithmetick is not to be the less

valued

valued that it is common, and is allowed to be one of the moſt clear and evident of the ſciences. But as a number of ſymbols are admitted into this ſcience, being neceſſary for giving it that extent and generality which is its greateſt excellence; the import of thoſe ſymbols is to be clearly ſtated, that no obſcurity or error may ariſe from the frequent uſe and complication of them.

§ 2. In GEOMETRY, lines are repreſented by a line, triangles by a triangle, and other figures by a figure of the ſame kind; but, in ALGEBRA, quantities are repreſented by the ſame letters of the alphabet; and various ſigns have been imagined for repreſenting their affections, relations, and dependencies. In Geometry the repreſentations are more natural, in Algebra more arbitrary: the former are like the firſt attempts towards the expreſſion of objects, which was by drawing their reſemblances; the latter correſpond more to the preſent uſe of languages and writing. Thus the evidence of Geometry is ſometimes more ſimple and obvious; but the uſe of Algebra more extenſive, and often more ready: eſpecially ſince the mathematical ſciences have acquired ſo vaſt an extent, and have been applied to ſo many enquiries.

§ 3. In thoſe ſciences, it is not barely magnitude that is the object of contemplation: but there

there are many affections and properties of quantities, and operations to be performed upon them, that are neceſſarily to be conſidered. In eſtimating the ratio or proportion of quantities, magnitude only is conſidered (*Elem.* 5. *Def.* 3.) But the nature and properties of figures depend on the poſition of the lines that bound them, as well as on their magnitude. In treating of motion, the direction of motion as well as its velocity; and the direction of powers that generate or deſtroy motion, as well as their forces, muſt be regarded. In OPTICS, the poſition, brightneſs, and diſtinctneſs of images, are of no leſs importance than their bigneſs; and the like is to be ſaid of other ſciences. It is neceſſary therefore that other ſymbols be admitted into Algebra beſide the letters and numbers which repreſent the magnitude of quantities.

§ 4. The relation of equality is expreſſed by the ſign $=$; thus to expreſs that the quantity repreſented by $a$ is equal to that which is repreſented by $b$, we write $a=b$. But if we would expreſs that $a$ is greater than $b$, we write $a \sqsupset b$; and if we would expreſs algebraically that $a$ is leſs than $b$, we write $a \sqsubset b$.

§ 5. QUANTITY is what is made up of parts, or is capable of being greater or leſs. It is increaſed by *Addition*, and diminiſhed by *Subtraction*; which are therefore the two primary ope-

rations that relate to quantity. Hence it is, that any quantity may be ſuppoſed to enter into algebraic computations two different ways which have contrary effects; either as an *increment* or as a *decrement*; that is, as a quantity to be added or as a quantity to be ſubtracted. The ſign + *(plus)* is the mark of *Addition*, and the ſign − *(minus)* of *Subtraction*. Thus the quantity being repreſented by $a$, $+a$ imports that $a$ is to be added, or repreſents an increment; but $-a$ imports that $a$ is to be ſubtracted, and repreſents a decrement. When ſeveral ſuch quantities are joined, the ſigns ſerve to ſhew which are to be added, and which are to be ſubtracted. Thus $+a+b$ denotes the quantity that ariſes when $a$ and $b$ are both conſidered as increments, and therefore expreſſes the ſum of $a$ and $b$. But $+a-b$ denotes the quantity that ariſes when from the quantity $a$ the quantity $b$ is ſubtracted; and expreſſes the exceſs of $a$ above $b$. When $a$ is greater than $b$, then $a-b$ is itſelf an increment; when $a=b$, then $a-b=0$; and when $a$ is leſs than $b$, then $a-b$ is itſelf a decrement.

§ 6. As addition and ſubtraction are oppoſite, or an increment is oppoſite to a decrement, there is an analogous oppoſition between the affections of quantities that are conſidered in the mathematical ſciences. As between exceſs and defect; between the value of effects

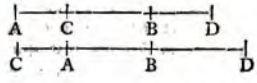
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or money due to a man, and money due by him; a line drawn towards the right, and a line drawn to the left; gravity and levity; elevation above the horizon, and depression below it. When two quantities equal in respect of magnitude, but of those opposite kinds, are joined together, and conceived to take place in the same subject, they destroy each other's effect, and their amount is *nothing*. Thus 100 *l.* due to a man and 100 *l.* due by him balance each other, and in estimating his stock may be both neglected. Power is sustained by an equal power acting on the same body with a contrary direction, and neither have effect. When two unequal quantities of those opposite qualities are joined in the same subject, the greater prevails by their difference. And when a greater quantity is taken from a lesser of the same kind, the remainder becomes of the opposite kind. Thus if we add the lines AB and BD together, their sum is AD; but if we are to subtract B D from AB,




then BC = BD is to be taken the contrary way towards A, and the remainder is AC; which, when BD, or BC exceeds AB, becomes a line on the other side of A. When two powers or forces are to be added together, their sum acts

upon the body: but when we are to ſubtract one of them from the other, we conceive that which is to be ſubtracted to be a power with an oppoſite direction; and if it be greater than the other, it will prevail by the difference. This change of quality however only takes place where the quantity is of ſuch a nature as to admit of ſuch a contrariety or oppoſition. We know nothing analogous to it in quantity abſtractly conſidered; and cannot ſubtract a greater quantity of matter from a leſſer, or a greater quantity of light from a leſſer. And the application of this doctrine to any art or ſcience is to be derived from the known principles of the ſcience.

§ 7. A quantity that is to be added is likewiſe called a *poſitive* quantity; and a quantity to be ſubtracted is ſaid to be *negative*: they are equally real, but oppoſite to each other, ſo as to take away each other's effect, in any operation, when they are equal as to quantity. Thus $3-3=0$, and $a-a=0$. But though $+a$ and $-a$ are equal as to quantity, we do not ſuppoſe in Algebra that $+a=-a$; becauſe to infer equality in this ſcience, they muſt not only be equal as to quantity, but of the ſame quality, that in every operation the one may have the ſame effect as the other. A decrement may be equal to an increment, but it has in all operations a contrary effect; a motion downwards

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ıot ſubtract a greater
leſſer, or a greater
ſer. And the appli-
y art or ſcience is to
vn principles of the

be added is like-
; and a quantity
*negative*: they are
each other, ſo as
fect, in any opera-
to quantity. Thus
But though $+a$
ntity, we do not
$a = -a$; becauſe
ce, they muſt not
but of the ſame
ition the one may
her. A decrement
, but it has in all
a motion *down-*
wards



wards may be equal to a motion upwards, and the depreſſion of a ſtar below the horizon may be equal to the elevation of a ſtar above it: but thoſe poſitions are oppoſite, and the diſtance of the ſtars is greater than if one of them was at the horizon ſo as to have no elevation above it, or depreſſion below it. It is on account of this contrariety that a negative quantity is ſaid to be leſs than nothing, becauſe it is oppoſite to the poſitive, and diminiſhes it when joined to it, whereas the addition of 0 has no effect. But a negative is to be conſidered no leſs as a real quantity than the poſitive. Quantities that have no ſign prefixed to them are underſtood to be poſitive.

§ 8. The number prefixed to a letter is called the numeral *coefficient*, and ſhews how often the quantity repreſented by the letter is to be taken. Thus $2a$ imports that the quantity repreſented by $a$ is to be taken twice; $3a$ that it is to be taken thrice; and ſo on. When no number is prefixed, *unit* is underſtood to be the coefficient. Thus 1 is the coefficient of $a$ or of $b$.

Quantities are ſaid to be *like* or *ſimilar*, that are repreſented by the ſame letter or letters equally repeated. Thus $+3a$ and $-5a$ are like; but $a$ and $b$, or $a$ and $aa$ are unlike.

A quantity is ſaid to conſiſt of as many *terms* as there are parts joined by the ſigns $+$

or $-$; thus $a+b$ consists of two terms, and is called a *binomial*; $a+b+c$ consists of three terms, and is called a *trinomial*. These are called *compound* quantities: a *simple* quantity consists of one term only, as $+a$, or $+ab$, or $+abc$.

The other symbols and definitions necessary in *Algebra* shall be explained in their proper places.

## CHAP. II.

### Of ADDITION.

§ 9. CASE I. To add quantities that are like and have like signs.

Rule. *Add together the coefficients, to their sum prefix the common sign, and subjoin the common letter or letters.*

EXAMPLES.

| | | | | | |
|---|---|---|---|---|---|
| To | $+5a$ | to | $-6b$ | to | $a+b$ |
| Add | $+4a$ | add | $-2b$ | add | $3a+5b$ |
| Sum | $+9a$ | Sum | $-8b$ | Sum | $4a+6b$ |

To

| | |
|---|---|
| To | $3a - 4x$ |
| Add | $5a - 8x$ |
| Sum | $8a - 12x$ |

Caſe II. To add quantities that are like but have unlike ſigns.

Rule. *Subtract the leſſer coefficient from the greater, prefix the ſign of the greater to the remainder, and ſubjoin the common letter or letters.*

EXAMPLES.

| | | |
|---|---|---|
| To | $-4a$ | $+5b-6c$ |
| Add | $+7a$ | $-3b+8c$ |
| Sum | $+3a$ | $2b+2c$ |

| | | |
|---|---|---|
| To | $a+6x-5y+8$ | $2a-2b$ |
| Add | $-5a-4x+4y-3$ | $-2a+2b$ |
| Sum | $-4a+2x-y+5$ | $0\ .\ .\ 0$ |

This rule is eaſily deduced from the nature of poſitive and negative quantities.

If there are more than two quantities to be added together, firſt add the poſitive together into one ſum, and then the negative (by *Caſe* I.) Then add theſe two ſums together (by *Caſe* II.)

EXAMPLE.

$$\begin{array}{r} +8a \\ -7a \\ +10a \\ -12a \\ \hline \text{Sum of the positive} \ldots +18a \\ \text{Sum of the negative} \ldots -19a \\ \hline \text{Sum of all} \ldots\ldots -a \end{array}$$

Case III. To add quantities that are unlike.

Rule. *Set them all down one after another, with their signs and coefficients prefixed.*

EXAMPLES.

| | | |
|---|---|---|
| To | $+2a$ | $+3a$ |
| Add | $+3b$ | $-4x$ |
| Sum | $2a+3b$ | $3a-4x$ |

| | |
|---|---|
| To | $4a+4b+3c$ |
| Add | $-4x-4y+3z$ |
| Sum | $4a+4b+3c-4x-4y+3z$ |

PLE.

$+8a$
$-7a$
$+10a$
$-12a$

e . . . $+18a$
e . . . $-19a$
. . . $-a$

ies that are unlike.

e after another, with fixed.

, E S.

$+3a$
$-4x$
$3a-4x$

$-4x-4y+3z$

CHAP.



## CHAP. III.

### Of Subtraction.

§ 10. GEnerale rule. *Change the ſigns of the quantity to be ſubtracted into their contrary ſigns, and then add it ſo changed to the quantity from which it was to be ſubtracted (by the rules of the laſt chapter:) the ſum ariſing by this addition is the remainder.* For, to ſubtract any quantity, either poſitive or negative, is the ſame as to add the oppoſite kind.

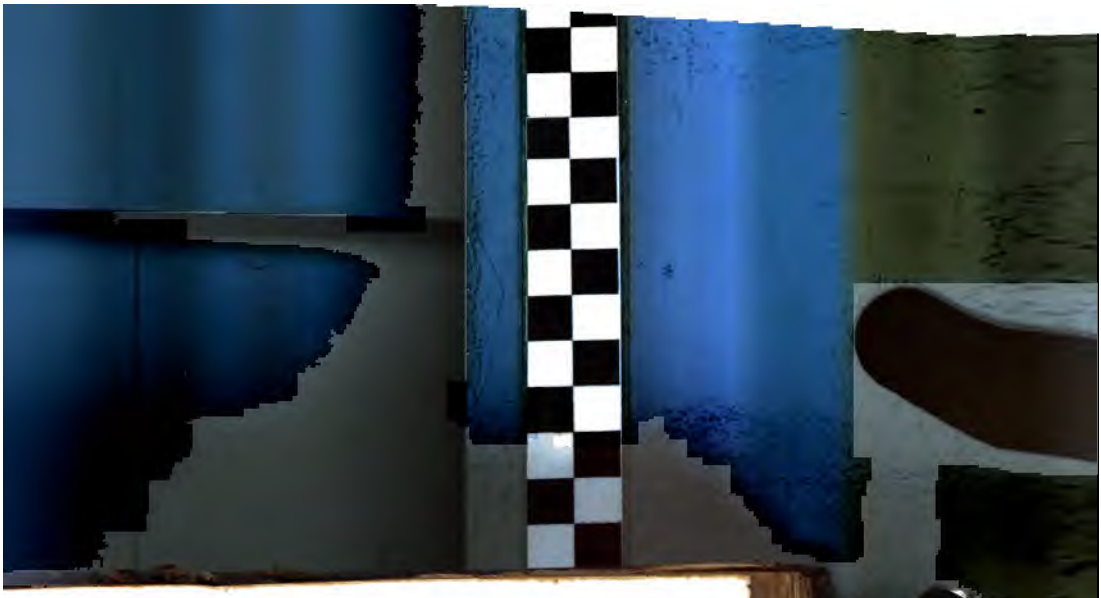
EXAMPLES.

| | | |
|---|---|---|
| From | $+5a$ | $8a-7b$ |
| Subtract | $+3a$ | $3a+4b$ |
| Remaind. | $5a-3a$, or $2a$ | $5a-11b$ |

| | |
|---|---|
| From | $2a-3x+5y-6$ |
| Subtract | $6a+4x+5y+4$ |
| Remaind. | $-4a-7x \quad 0 \quad -10$ |

It is evident, that to ſubtract or take away a decrement is the ſame as adding an equal increment. If we take away $-b$ from $a-b$, there remains $a$; and if we add $+b$ to $a-b$, the ſum is likewiſe $a$. In general, the ſubtraction of a negative quantity is equivalent to adding its poſitive value.

CHAP.





IV.

ICATION.

the General rule for
at *when the ſigns of*
both +, or both −,)
; but *when the ſigns*
*the ſign of the product*

re quantity, $+a$, is
ly poſitive number,
g is, That $+a$ is to
y times as there are
the product is evi-

ultiplied by $n$, then
as often as there are
he product muſt be

poſitive number im-
ldition: but multi-
gative implies a re-
. And when $+a$ is
by $-n$, the mean-
is to be ſubtracted as
units in $n$: there-
fore



fore the product is negative, being $-na$.

Caſe IV. When $-a$ is to be multiplied by $-n$, then $-a$ is to be ſubtracted as often as there are unites in $n$; but (by § 10.) to ſubtract $-a$ is equivalent to adding $+a$, conſequently the product is $+na$.

The IId and IVth caſes may be illuſtrated in the following manner.

By the definitions, $+a-a=0$; therefore, if we multitply $+a-a$ by $n$, the product muſt vaniſh or be 0, becauſe the factor $a-a$ is 0. The firſt term of the product is $+na$ (by Caſe I.) Therefore the ſecond term of the product muſt be $-na$, which deſtroys $+na$; ſo that the whole product muſt be $+na-na=0$. Therefore $-a$ multiplied by $+n$ gives $-na$.

In like manner, if we multiply $+a-a$ by $-n$, the firſt term of the product being $-na$, the latter term of the product muſt be $+na$, becauſe the two together muſt deſtroy each other, or their amount be 0, ſince one of the factors (*viz.* $a-a$) is 0. Therefore $-a$ multiplied by $-n$ muſt give $+na$.

In this general doctrine the multiplicator is always conſidered as a number. A quantity of any kind may be multiplied by a number: but

a pound is not to be multiplied by a pound, or a debt by a debt, or a line by a line. We ſhall afterwards conſider the analogy there is betwixt rectangles in Geometry and a product of two factors.

§ 12. If the quantities to be multiplied are *ſimple* quantities, *find the ſign of the product by the laſt rule; after it place the product of the coefficients, and then ſet down all the letters after one another as in one word.*

## EXAMPLES.

| | | | |
|---|---|---|---|
| Mult. | $+a$ | $-2a$ | $6x$ |
| By | $+b$ | $+4b$ | $-5a$ |
| Prod. | $+ab$ | $-8ab$ | $-30ax$ |

| | | |
|---|---|---|
| Mult. | $-8x$ | $+3ab$ |
| By | $-4a$ | $-5ac$ |
| Prod. | $+32ax$ | $-15aabc$ |

§ 13. To multiply *compound* quantities, you muſt *multiply every part of the multiplicand by all the parts of the multiplier taken one after another, and then collect all the products into one ſum: that ſum ſhall be the product required.*

EX-

multiplied by a pound,
r a line by a line. We
der the analogy there is
Geometry and a product

ties to be multiplied are
*he sign of the product by*
*ace the product of the co-*
*down all the letters after*
*d.*

PLES.

$$\begin{array}{r|r} -2a & 6x \\ -4b & -5a \\ \hline 8ab & -30ax \end{array}$$

$$\begin{array}{|r} +3ab \\ -5ac \\ \hline -15aabc \end{array}$$

*ound* quantities, you
*of the multiplicand by*
*ier taken one after an-*
*the products into one*
*roduct required.*

EX-



## EXAMPLES.

| | | |
|---|---|---|
| Mult. | $a+b$ | $2a-3b$ |
| By | $a+b$ | $4a+5b$ |
| Prod. | $aa+ab$ | $8aa-12ab$ |
| | $+ab+bb$ | $+10ab-15bb$ |
| Sum | $aa+2ab+bb$ | $8aa-2ab-15bb$ |

| | | |
|---|---|---|
| Mult. | $2a-4b$ | $xx-ax$ |
| By | $2a+4b$ | $x+a$ |
| Prod. | $4aa-8ab$ | $xxx-axx$ |
| | $+8ab-16bb$ | $+axx-aax$ |
| Sum | $4aa\,..\,0-16bb$ | $xxx\,..\,0-aax$ |

| | |
|---|---|
| Mult. | $aa+ab+bb$ |
| By | $a-b$ |
| Prod. | $aaa+aab+abb$ |
| | $-aab-abb-bbb$ |
| Sum | $aaa\,..\,0\,..\,0-bbb$ |

§ 14. Products that arise from the multiplication of two, three, or more quantities, as *abc*, are said to be of two, three, or more *dimensions*; and those quantities are called *factors* or *roots*.

If all the factors are equal, then these products are called *powers*; as *aa* or $a^2$ are powers of *a*. Powers are expressed sometimes by placing above the root to the right-hand a figure expressing the number of factors that produce them. Thus,

| | | | | |
|---|---|---|---|---|
| *a* | is called the | 1st | Power of the root *a*, and is shortly expressed thus, | $a$ |
| *aa* | | 2d | | $a^2$ |
| *aaa* | | 3d | | $a^3$ |
| *aaaa* | | 4th | | $a^4$ |
| *aaaaa* | | 5th | | $a^5$ |

§ 15. These figures which express the number of factors that produce powers are called their *indices* or *exponents*; thus 2 is the index of $a^2$. And *powers of the same root are multiplied by adding their exponents*. Thus $a^2 \times a^3 = a^5$, $a^4 \times a^3 = a^7$, $a^3 \times a = a^4$.

§ 16. Sometimes it is useful not actually to multiply compound quantities, but to set them down with the sign of multiplication (×) between them, drawing a line over each of the compound factors. Thus $\overline{a+b} \times \overline{a-b}$ expresses the product of $a+b$ multiplied by $a-b$.

CHAP.

: equal, then theſe pro-
; as *aa* or *aaa* are pow-
:xpreſſed ſometimes by
) the right-hand a figure
of factors that produce

Power of the root *a*, and is ſhortly expreſſed thus, $\left\{\begin{matrix} a \\ a^2 \\ a^3 \\ a^4 \\ a^5 \end{matrix}\right.$

hich expreſs the num-
ace powers are called
hus 2 is the index of
*me root are multiplied*
Thus $a^2 \times a^1 = a^3$,

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e over each of the
$\overline{a+b} \times \overline{a-b}$ ex-
$+b$ multiplied by





## CHAP. V.

### Of DIVISION.

§ 17. THE ſame rule for the ſigns is to be obſerved in Diviſion as in Multiplication; that is, *If the ſigns of the dividend and diviſor are like, the ſign of the quotient muſt be +; if they are unlike, the ſign of the quotient muſt be —.* This will be eaſily deduced from the rule in Multiplication, if you conſider that the quotient muſt be ſuch a quantity as multiplied by the diviſor ſhall give the dividend.

§ 18. The General rule in Diviſion is, *to place the dividend above a ſmall line, and the diviſor under it, expunging any letters that may be found in all the quantities of the dividend and diviſer, and dividing the coefficients of all the terms by any common meaſure.* Thus when you divide $10ab+15ac$ by $2ad$, expunging $a$ out of all the terms, and dividing all the coefficients by 5, the quotient is $\frac{2b+3c}{4d}$; and

$$2b)ab+bb\left(\frac{a+b}{2}.\right.$$

$$12ab)30ax-54ay\left(\frac{5x-9y}{2b}.\right.$$

$\frac{b+3c}{2a}$.

$\frac{a}{b}$.

*me root are divided by as they are multiplied* you divide $a^5$ by $a^2$, And $b^5$ divided by $a^7b^5$ divided by $a^2b^3$

*be divided is com- its parts according to f its letters, as in the ividend* $a^2+2ab+b^2$, *to the dimenſions of a is of two dimen- b where it is not at all, here it is not at all, a + b, must be ranged the ſame letters; then m of the dividend by nd to ſet down the ple, is a; then mul- le diviſor, and ſub- widend, and the re- end, which in this*

$a+b)$



$$a+b)a^2+2ab+b^2(a+b$$
$$a^2+\ ab$$
$$ab+b^2$$
$$ab+b^2$$
$$0\quad 0$$

*Divide the firſt term of this new dividend by the firſt term of the diviſor and ſet down the quotient (which in this example is b) with its proper ſign. Then multiply the whole diviſor by this part of the quotient, and ſubtract the product from the new dividend; and if there is no remainder, the diviſion is finiſhed:* If there is a remainder, you are to proceed after the ſame manner till no remainder is left; or till it appear that there will be always ſome remainder.

Some Examples will illuſtrate this operation.

## EXAMPLE I.

$$a+b)a^2-b^2(a-b$$
$$a^2+ab$$
$$-ab-b^2$$
$$-ab-b^2$$
$$0\quad 0$$

## EXAMPLE II.

$$
\begin{array}{l}
a-b)\,aaa-3aab+3abb-bbb\,(aa-2ab+bb \\
\quad aaa-\ aab \\
\hline
\quad -2aab+3abb-bbb \\
\quad -2aab+2abb \\
\hline
\qquad\qquad abb-bbb \\
\qquad\qquad abb-bbb \\
\hline
\qquad\qquad 0\quad 0
\end{array}
$$

## EXAMPLE III.

$$
\begin{array}{l}
a-b)\,aaa-bbb\,(aa+ab+bb \\
\quad aaa-aab \\
\hline
\qquad aab-bbb \\
\qquad aab-abb \\
\hline
\qquad\quad abb-bbb \\
\qquad\quad abb-bbb \\
\hline
\qquad\quad 0\quad 0
\end{array}
$$

EX-

PLE II.

$bb-bbb\,(aa-2ab+bb$

$bb-bbb$
$bb$

$bb-bbb$
$bb-bbb$

o o

LE III.

$(aa+ab+bb$

$b-bbb$
$b-abb$

$abb-bbb$
$abb-bbb$

o o

EX-



## EXAMPLE IV.

$3a-6)\,6aaaa-96\,(2aaa+4aa+8a+16$
$6aaaa-12aaa$

$12aaa-96$
$12aaa-24aa$

$24aa-96$
$24aa-48a$

$48a-96$
$48a-96$

o o

§ 21. It often happens that the operation may be continued without end, and then you have an *infinite Series* for the quotient; and *by comparing the first three or four terms you may find what law the terms observe: by which means, without any more division, you may continue the quotient as far as you please.* Thus, in dividing 1 by $1-a$, you find the quotient to be $1+a+aa+aaa+aaaa+$ &c. which Series can be continued as far as you please by adding the powers of $a$.

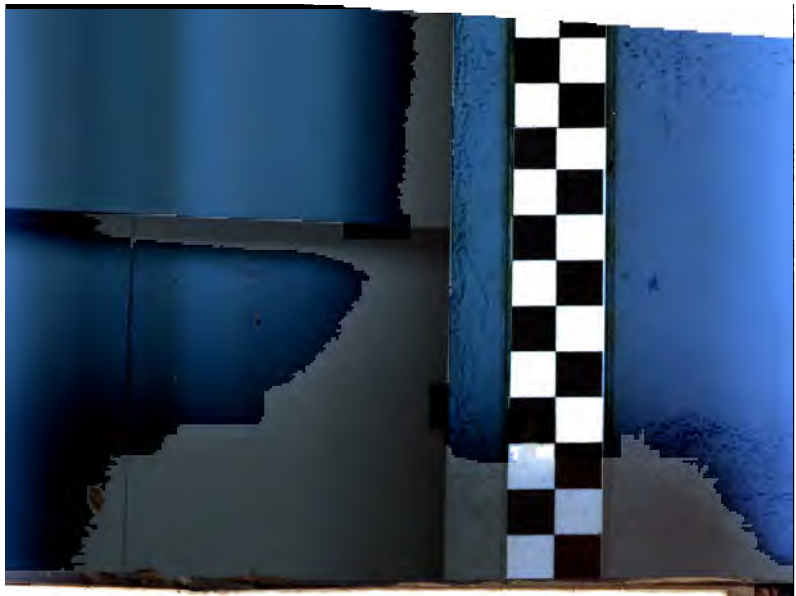
The operation is thus:

$$
\begin{array}{l}
1-a\,)\,1\,(1+a+aa+aaa,\ \&c.\\
\quad 1-a\\
\quad\overline{\phantom{1-a}}\\
\quad\ +a\\
\quad\ +a-aa\\
\quad\overline{\phantom{+a-aa}}\\
\quad\ \ +aa\\
\quad\ \ +aa-aaa\\
\quad\overline{\phantom{+aa-aaa}}\\
\quad\ \ \ +aaa\\
\quad\ \ \ +aaa-aaaa\\
\quad\overline{\phantom{+aaa-aaaa}}\\
\quad\ \ \ \ +aaaa,\ \&c.
\end{array}
$$

Another Example.

$$
\begin{array}{l}
a+x\,)\,aa+xx\,(a-x+\frac{2xx}{a}-\frac{2x^3}{a^2}+\frac{2x^4}{a^3}-\&c.\\
\quad aa+ax\\
\quad\overline{\phantom{aa+ax}}\\
\quad\ -ax+xx\\
\quad\ -ax-xx\\
\quad\overline{\phantom{-ax-xx}}\\
\quad\ \ +2xx\\
\quad\ \ +2xx-\frac{2x^3}{a}\\
\quad\overline{\phantom{+2xx-\frac{2x^3}{a}}}\\
\quad\ \ \ -\frac{2x^3}{a}\\
\quad\ \ \ -\frac{2x^3}{a}-\frac{2x^4}{a^2}\\
\quad\overline{\phantom{-\frac{2x^3}{a}-\frac{2x^4}{a^2}}}\\
\quad\ \ \ \ +\frac{2x^4}{a^2}\\
\quad\ \ \ \ \&c.
\end{array}
$$

In





ion is thus:
$+aa+aaa$, &c.

$-aaa$

$+aaa$
$+aaa-aaaa$

$+aaaa$, &c.

ample.

$\frac{xx}{1}-\frac{2x^3}{a^2}+\frac{2x^4}{a^3}$ &c.

$-\frac{2x^6}{a^5}$

$+\frac{2x^6}{a^5}$
&c.

Ia



In this laſt example the ſigns are alternately + and −, the coefficient is conſtantly 2, after the firſt two terms, and the letters are the powers of $x$ and $a$; ſo that the quotient may be continued as far as you pleaſe without any more diviſion.

But in Diviſion, after you come to a remainder of one term, as $2xx$ in the laſt example, it is commonly ſet down with the diviſor under it, after the other terms, and theſe together give the quotient. Thus, the quotient in the laſt example is found to be $a-x+\frac{2x^2}{a+x}$. And $bb+ab$ divided by $b-a$ gives for the quotient $b+\frac{2ab}{b-a}$.

*Note*, The ſign ÷ placed between any two quantities, expreſſed the quotient of the former divided by the latter. Thus $\overline{a+b}\div\overline{a-x}$ is the quotient of $a+b$ divided by $a-x$.

## CHAP. VI.

### Of FRACTIONS.

§ 22. IN the laſt Chapter it was ſaid that the quotient of any quantity *a* divided by *b* is expreſſed by placing *a* above a ſmall line and *b* under it, thus, $\frac{a}{b}$. Theſe quotients are alſo called *Fractions*; and the dividend or quantity placed above the line is called the *Numerator* of the fraction, and the diviſor or quantity placed under the line is called the *Denominator*. Thus $\frac{2}{3}$ expreſſed the quotient of 2 divided by 3; and 2 is the numerator and 3 the denominator of the fraction.

§ 23. *If the numerator of a fraction is equal to the denominator, then the fraction is equal to unity. Thus* $\frac{a}{a}$ *and* $\frac{b}{a}$ *are equal to unit. If the numerator is greater than the denominator, then the fraction is greater than unit.* In both theſe caſes, the fraction is called *improper*. But *if the numerator is leſs than the denominator, then the fraction is leſs than unit*, and is called *proper*. Thus $\frac{5}{3}$ is an improper fraction; but $\frac{3}{4}$ and $\frac{2}{3}$ are proper fractions. A *mixt* quantity is that



whereof

ATISE *of* Part I.

P. VI.

CTIONS.

apter it was ſaid that the
ıy quantity *a* divided by
*a* above a ſmall line and

Theſe quotients are alſo
he dividend or quantity
called the *Numerator.*
ıe diviſor or quantity
called the *Denominator.*
otient of 2 divided by 3;
d 3 the denominator of

*of a fraction is equal*
*the fraction is equal to*
*equal to unit. If the*
*the denominator, then*
*unit.* In both theſe
led *improper.* But *if*
*the denominator, then*
and is called *proper.*
fraction; but $\frac{3}{4}$ and

*mixt* quantity is that
whereof



whereof one part is an *integer* and the other a *fraction.* As $3\frac{1}{4}$ and $5\frac{2}{3}$, and $a+\frac{a^2}{b}$.

## PROBLEM I.

§ 24. *To reduce a* MIXT *quantity to an* IMPROPER FRACTION.

Rule. *Multiply the part that is an integer by the denominator of the fractional part; and to the product add the numerator; under their ſum place the former denominator.*

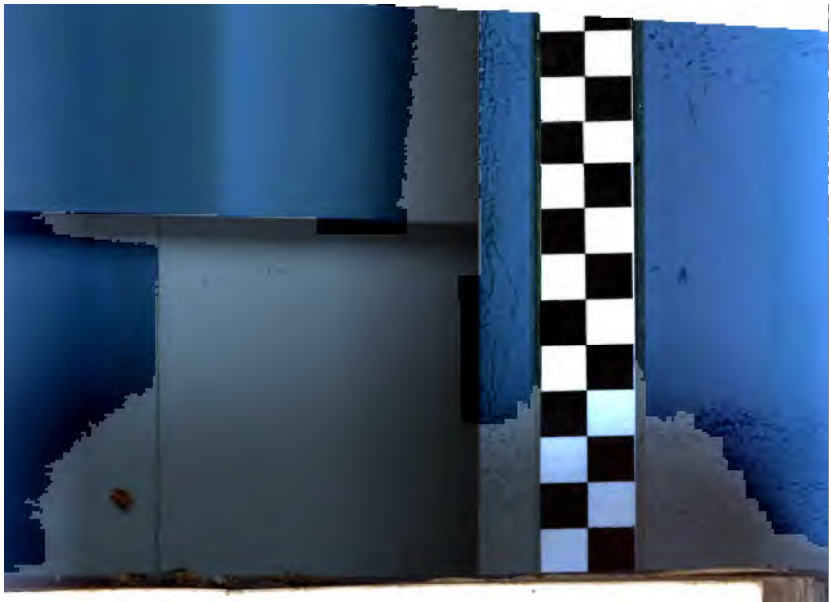
Thus $2\frac{3}{5}$ reduced to an improper fraction, gives $\frac{13}{5}$; $a+\frac{a^2}{b}=\frac{ab+a^2}{b}$; and $a-x+\frac{a^2-ax}{x}=\frac{a^2-x^2}{x}$.

## PROBLEM II.

§ 25. *To reduce an* IMPROPER *fraction to a* MIXT QUANTITY.

Rule. *Divide the numerator of the fraction by the denominator, and the quotient ſhall give the integral part; the remainder ſet over the denominator ſhall be the fractional part.*

Thus $\frac{12}{5}=2\frac{2}{5}$; $\frac{ab+a^2}{b}=a+\frac{a^2}{b}$; $\frac{ax+2xx}{a+x}=x+\frac{x^2}{a+x}$; $\frac{aa+xx}{a-x}=a+x+\frac{2xx}{a-x}$.





EM III.

ons of different denomina-
ual value that ſhall have

nerator, ſeparately taken,
but its own, and the
new numerators. Then
ators into one another,
e the common denomina-

, $\frac{c}{d}$, are reſpectively
$\frac{cd}{cd}$, $\frac{bbd}{bcd}$, $\frac{ccb}{bcd}$, which
bcd. And the fractions
equal to theſe $\frac{40}{60}$,

M IV.
RACT Fractions,
ommon denominator,
numerators, the ſum
ommon denominator,
ired.

Thus





Thus $\frac{a}{b}+\frac{c}{d}+\frac{d}{e}=\frac{ade+bce+d^2b}{bde}$;

$\frac{a}{b}-\frac{c}{d}=\frac{ad-bc}{bd}$; $\frac{2}{3}+\frac{3}{4}=\frac{8+9}{12}=\frac{17}{12}$

$=1\frac{5}{12}$: $\frac{3}{4}-\frac{2}{3}=\frac{9-8}{12}=\frac{1}{12}$;

$\frac{4}{5}-\frac{3}{4}=\frac{16-15}{20}=\frac{1}{20}$;

$\frac{x}{2}-\frac{x}{3}=\frac{3x-2x}{6}=\frac{x}{6}$.

## PROBLEM V.

§ 28. *To* MULTIPLY *Fractions.*

Rule. *Multiply their numerators one into another to obtain the numerator of the product; and their denominators multiplied into one another ſhall give the denominator of the product.*

Thus $\frac{a}{b}\times\frac{c}{d}=\frac{ac}{bd}$; $\frac{2}{3}\times\frac{4}{5}=\frac{8}{15}$; and $\frac{a+b}{c}\times\frac{a-b}{d}=\frac{a^2-b^2}{cd}$.

If a mixt quantity is to be multiplied, firſt reduce it to the form of a fraction (by *Prob.* 1.) And if an integer is to be multiplied by a fraction, you may reduce it to the form of a fraction by placing unit under it.

EXAMPLES.

$5\frac{2}{7}\times\frac{3}{4}=\frac{17}{3}\times\frac{3}{4}=\frac{51}{12}$; $9\times\frac{2}{3}=\frac{9}{1}\times\frac{2}{3}$

$=$

$= \frac{18}{3} \div 6 : \overline{b + \frac{bx}{a}} \times \frac{a}{x} = \frac{ba + bx}{a} \times \frac{a}{x} = \frac{a^2b + abx}{ax} = \frac{ab + bx}{x}$.

## PROBLEM VI.

### § 29. *To* DIVIDE *Fractions.*

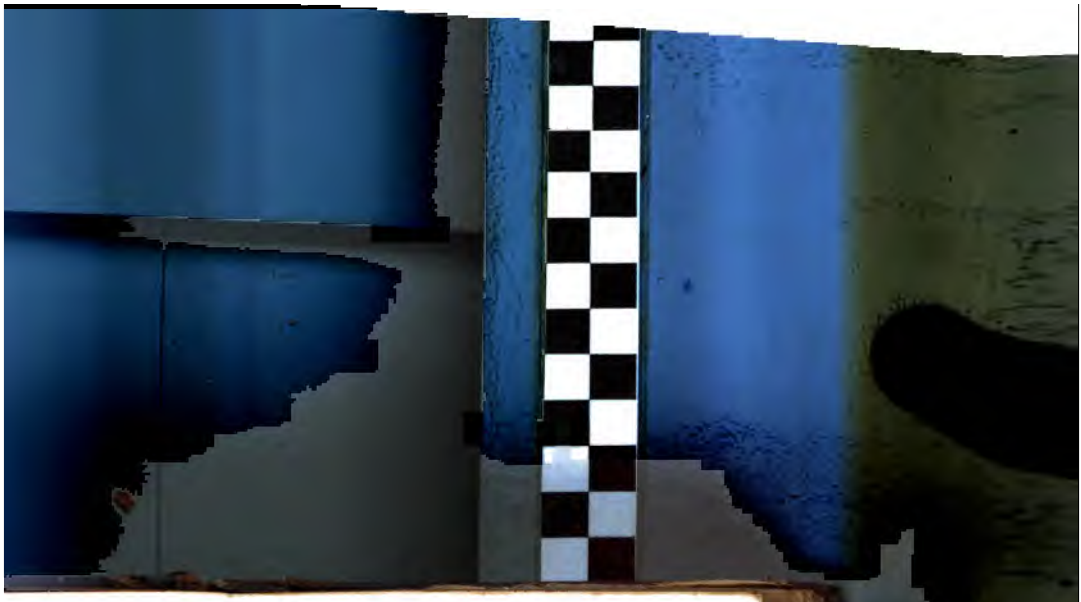
Rule. *Multiply the numerator of the dividend by the denominator of the divisor, their product ſhall give the numerator of the quotient. Then multiply the denominator of the dividend by the numerator of the divisor, and their product ſhall give the denominator.*

Thus $\frac{4}{5}\Big)\frac{2}{3}\Big(\frac{10}{12}$; $\frac{3}{7}\Big)\frac{5}{8}\Big(\frac{35}{24}$; $\frac{c}{d}\Big)\frac{a}{b}\Big(\frac{ad}{cb}$; $\frac{a+b}{a-b}\Big)\frac{a-b}{a}\Big(\frac{a^2-2ab+b^2}{a^2+ab}$.

§ 30. Theſe laſt four Rules are eaſily demonſtrated from the definition of a fraction.

1. It is obvious that the fractions $\frac{a}{b}$, $\frac{c}{d}$, $\frac{e}{f}$, are reſpectively equal to $\frac{adf}{bdf}$, $\frac{cbf}{dbf}$, $\frac{ebd}{fbd}$, ſince if you divide *adf* by *bdf*, the quotient will be the ſame as of *a* divided by *b*; and *cbf* divided by *dbf* gives the ſame quotient as *c* divided by *d*; and *ebd* divided by *fbd* the ſame quotient as *e* divided by *f*.

2. Fractions reduced to the ſame denominator are added by adding their numerators and ſub-





$\frac{a}{x} = \frac{ba+bx}{a} \times \frac{a}{x} =$

EM VI.

IDE *Fractions.*

*verator of the dividend by e divisor, their product r of the quotient. Then ir of the dividend by the , and their product ſhall*

$\frac{5}{8}\left(\frac{35}{24}\right.$; $\left.\frac{c}{d}\right)\frac{a}{b}\left(\frac{ad}{cb}\right.$;

$\frac{}{a^2+ab}$.

ules are eaſily demon- of a fraction.

ie fractions $\frac{a}{b}$, $\frac{c}{d}$, $\frac{e}{f}$,

$\frac{}{f}$, $\frac{cbf}{dbf}$, $\frac{ebd}{fbd}$, ſince if quotient will be the and $cbf$ divided by as $c$ divided by $d$; ime quotient as $e$ di-

the ſame denomina- heir numerators and ſub-



ſubſcribing the common denominator. I ſay $\frac{a}{b} + \frac{c}{b} = \frac{a+c}{b}$. For call $\frac{a}{b} = m$, and $\frac{c}{b} = n$, and it will be $a = mb$, $c = nb$, and $mb + nb = a + c$, and $m + n = \frac{a+c}{b}$; that is, $\frac{a}{b} + \frac{c}{b} = \frac{a+c}{b}$. After the ſame manner, $\frac{a}{b} - \frac{c}{b} = m - n = \frac{a-c}{b}$.

3. I ſay $\frac{a}{b} \times \frac{c}{d} (= m \times n) = \frac{ac}{bd}$; for $bm = a$, $dn = c$; and $bdmn = ac$, and $mn = \frac{ac}{bd}$; that is, $\frac{a}{b} \times \frac{c}{d} = \frac{ac}{bd}$.

4. I ſay $\frac{a}{b}$ divided by $\frac{c}{d}$, or $\frac{m}{n}$, gives $\frac{ad}{cb}$; for $mb = a$, and $mbd = ad$; $nd = c$, and $nbd = cb$; therefore $\frac{mbd}{nbd} = \frac{ad}{cb}$; that is, $\frac{m}{n} = \frac{ad}{cb}$.

## PROBLEM VII.

§ 31. *To find the greateſt common Meaſure of two numbers*; that is, the greateſt number that can divide them both without a remainder.

Rule. *Firſt divide the greater number by the leſſer, and if there is no remainder the leſſer number is the greateſt common diviſor required.*

*If*

which divided by $-2b$ is reduced to

$$a-b)\ a^2-b^2\ (a+b$$
$$a^2-b^2$$
$$0\quad 0$$

Therefore $a-b$ is the greateſt common meaſure required.

The ground of this operation is, That any quantity that meaſures the diviſor and the remainder (if there is any) muſt alſo meaſure the dividend; becauſe the dividend is equal to the ſum of the diviſor multiplied into the quotient, and of the remainder added together*. Thus in the laſt example, $a-b$ meaſures the diviſor $a^2-b^2$, and the remainder $-2ab+2b$; it muſt therefore likewiſe meaſure their ſum $a^2-2ab+b^2$. You muſt obſerve in this operation to make that the dividend which has the higheſt powers of the letter, according to which the quantities are ranged.

## PROBLEM VIII.

§ 33. *To reduce any Fraction to its loweſt terms.*

Rule. *Find the greateſt common meaſure of the numerator and denominator; divide them by that common meaſure and place the quotients in their room, and you ſhall have a fraction equivalent*

* See Chap. XIV.

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*to the given fraction expreſſed in the leaſt terms.*

Thus $\frac{25bc)}{25bc)}\frac{75abc}{125bcx} = \frac{3a}{5x}$; $\frac{156aa+156ab}{572aa-572ab} = \frac{3a+3b}{11a-11b}$; $\frac{a^2-b^2}{a^2-2ab+b^2} = \frac{a+b}{a-b}$; $\frac{a^3-b^3a}{a^2+2ab+b^2} = \frac{a^2-ba}{a+b}$; $\frac{a^4-b^4}{a^3-a^3b^2} = \frac{a^2+b^2}{a^3}$.

When unit is the greateſt common meaſure of the numbers and quantities, then the fraction is already in its loweſt terms. Thus $\frac{3ab}{5c}$ can not be reduced lower.

And numbers whoſe greateſt common meaſure is unit, are ſaid to be *prime* to one another.

§ 34. If it is required to reduce a given fraction to a fraction equal to it that ſhall have a given denominator, you muſt *multiply the numerator by the given denominator, and divide the produƈt by the former denominator, the quotient ſet over the given denominator is the fraction required.* Thus $\frac{a}{b}$ being given, and it being required to reduce it to an equal fraction whoſe denominator ſhall be $c$; find the quotient of $ac$ divided by $b$, and it ſhall be the numerator of the fraction required.

If

*on expreſſed in the leaſt*

$= \frac{3a}{5x}$ ; $\frac{156aa+156ab}{572aa-572ab} =$

$\frac{a^2-b^2}{a^2-2ab+b^2} = \frac{a+b}{a-b}$ ;

$\frac{a^4-b^4}{a^3-a^2b^2} = \frac{a^2+b^2}{a^2}$.

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terms. Thus $\frac{3ab}{5ac}$ can

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equal fraction whoſe de-
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If a Vulgar fraction is to be reduced to a decimal (that is, a fraction whoſe denominator is 10, or any of its powers) *annex as many cyphers as you pleaſe to the numerator, and then divide it by the denominator, the quotient ſhall give a decimal equal to the Vulgar fraction propoſed.*

Thus $\frac{2}{3} = .66666$, *&c.*; $\frac{3}{5} = .6$;

$\frac{2}{7} = .2857142$, *&c.*

§ 35. Theſe fractions are added and ſubtracted like whole numbers; only care muſt be taken to *ſet ſimilar places above one another*, as units above units, and tenths above tenths, *&c.* They are multiplied and divided as integer numbers; only *there muſt be as many decimal places in the product as in both the multiplicand and multiplier*; and *in the quotient as many as there are in the dividend more than in the diviſor.* And in diviſion the quotient may be continued to any degree of exactneſs you pleaſe, by adding cyphers to the dividend. The ground of theſe operations is eaſily underſtood from the general rules for adding, multiplying, and dividing fractions.

CHAP.

## CHAP. VII.

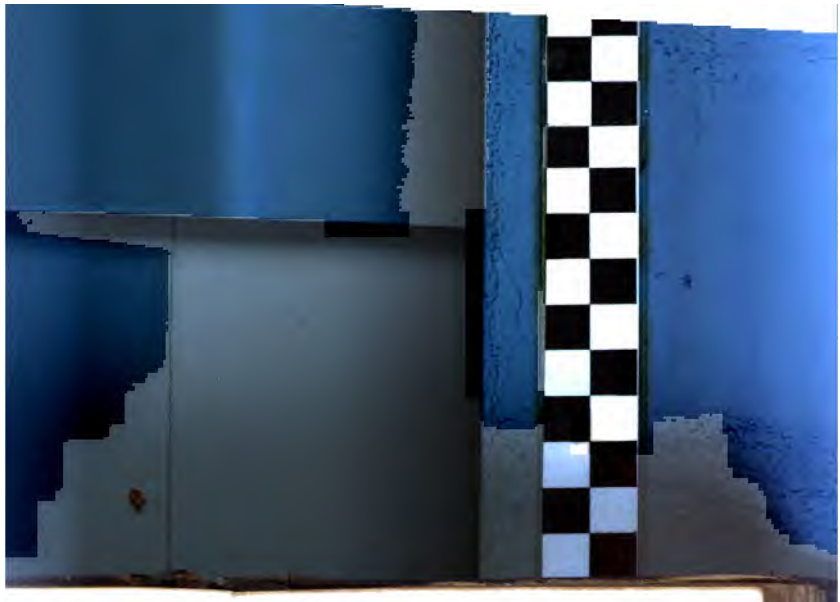
### Of the INVOLUTION of Quantities.

§ 36. THE products arising from the continual multiplication of the same quantity were called (in *Chap.* 4.) the *powers* of that quantity. Thus $a$, $a^2$, $a^3$, $a^4$, &c. are the powers of $a$; and $ab$, $a^2b^2$, $a^3b^3$, $a^4b^4$, &c. are the powers of $ab$. In the same Chapter, the rule for the multiplication of powers of the same quantity is to "Add the exponents and make their sum the exponent of the product." Thus $a^2 \times a^3 = a^5$; and $a^2b^2 \times a^3b^3 = a^5b^5$. In *Chap.* 5. you have the rule for dividing powers of the same quantity, which is, "To subtract the exponents and make the difference the exponent of the quotient."

Thus $\frac{a^5}{a^4} = a^{5-4} = a^1$; and $\frac{a^2b^2}{a^3b} = a^{2-3}b^{2-1} = ab^1$.

§ 37. *If you divide a lesser power by a greater, the exponent of the quotient must*, by this Rule, *be negative*. Thus $\frac{a^2}{a^5} = a^{2-5} = a^{-3}$. But $\frac{a^3}{a^5} = \frac{1}{a^2}$; and hence $\frac{1}{a^2}$ is expressed also by $a^{-2}$ with a negative exponent.

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A P. VII.

TION of Quantities.

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$ab$. In the ſame Chapter,
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- Add the exponents and
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and $a^2b^2 \times a^3b^3 = a^5b^5$.
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$= a^3$; and $\frac{a^5b^5}{a^2b} =$

*r leſſer power by a greater,*
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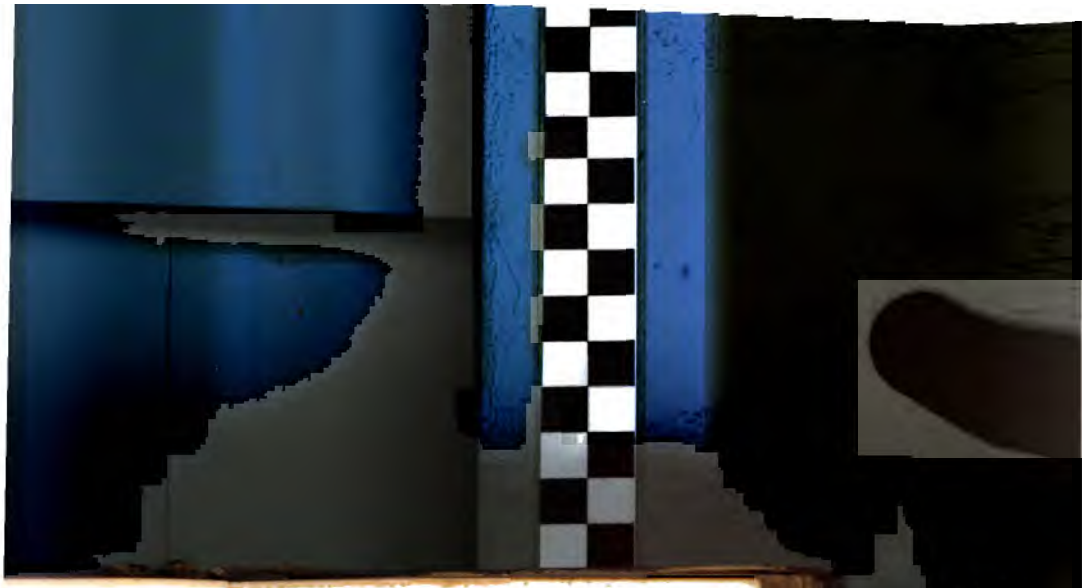
It is alſo obvious that $\frac{a}{a} = a^{1-1} = a^0$; but $\frac{a}{a} = 1$, and therefore $a^0 = 1$. After the ſame manner $\frac{1}{a} = \frac{a^0}{a} = a^{0-1} = a^{-1}$; $\frac{1}{aa} = \frac{a^0}{a^2} = a^{0-2} = a^{-2}$; $\frac{1}{aaa} = a^{0-3} = a^{-3}$; ſo that the quantities $a$, $1$, $\frac{1}{a}$, $\frac{1}{a^2}$, $\frac{1}{a^3}$, $\frac{1}{a^4}$, &c. may be expreſſed thus, $a^1$, $a^0$, $a^{-1}$, $a^{-2}$, $a^{-3}$, $a^{-4}$, &c. Thoſe are called the *negative* powers of $a$ which have negative exponents; but they are at the ſame time *poſitive* powers of $\frac{1}{a}$ or $a^{-1}$.

§ 38. *Negative powers (as well as poſitive) are multiplied by adding, and divided by ſubtracting their exponents.* Thus the product of $a^{-2}$ (or $\frac{1}{a^2}$) multiplied by $a^{-3}$ (or $\frac{1}{a^3}$) is $a^{-2-3} = a^{-5}$ (or $\frac{1}{a^5}$); alſo $a^{-6} \times a^4 = a^{-6+4} = a^{-2}$ (or $\frac{1}{a^2}$); and $a^{-1} \times a^1 = a^0 = 1$. And, in general, *any poſitive power of a multiplied by a negative power of a of an equal exponent gives* UNIT *for the product*; for the poſitive and negative deſtroy each other, and the product gives $a^0$, which is equal to unit.

Likewiſe $\frac{a^{-3}}{a^{-2}} = a^{-3+2} = a^{-1} = \frac{1}{a^1}$; and $\frac{a^{-2}}{a^{-2}} = a^{-2+2} = a^0$. But alſo, $\frac{a^{-2}}{a^{-2}} = \frac{a^{-2}}{a^{-2} \times a^{-2}} = \frac{1}{a^{-2}}$; therefore $\frac{1}{a^{-2}} = a^2$: And, in general, "any quantity placed in the denominator of a fraction may be tranſpoſed to the numerator, if the ſign of its exponent be changed." Thus $\frac{1}{a^2} = a^{-2}$, and $\frac{1}{a^{-2}} = a^2$.

§ 39. The quantity $a^m$ expreſſes any power of $a$ in general; the exponent $(m)$ being undetermined; and $a^{-m}$ expreſſes $\frac{1}{a^m}$, or a negative power of $a$ of an equal exponent: and $a^m \times a^{-m} = a^{m-m} = a^0 = 1$ is their product. $a^n$ expreſſes any other power of $a$; $a^m \times a^n = a^{m+n}$ is the product of the powers $a^m$ and $a^n$, and $a^{m-n}$ is their quotient.

§ 40. To raiſe any ſimple quantity to its ſecond, third, or fourth power, is to add its exponent twice, thrice, or four times to itſelf; therefore the ſecond power of any quantity is had by doubling its exponent, and the third by trebling its exponent; and, in general, *the power expreſſed by m of any quantity is had by multiplying the exponent by m*, as is obvious from the multiplication of powers. Thus the ſecond power or ſquare of $a$ is $a^{2 \times 1} = a^2$; its third power





$: a^{-1+1} = a^{-1} = \frac{1}{a^1}$; and

. But alſo, $\frac{a^{-1}}{a^{-1}} = \frac{a^{-1}}{a^{-1} \times a^{-1}}$

$\frac{1}{a^1} = a^1$: And, in general,

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is $a^{2\times1} = a^2$; its third
power



power or cube is $a^{3\times1} = a^3$; and the $m$th power of $a$ is $a^{m\times1} = a^m$. Alſo, the ſquare of $a^4$ is $a^{2\times4} = a^8$; the cube of $a^4$ is $a^{3\times4} = a^{12}$; and the $m$th power of $a^4$ is $a^{4\times m}$. The ſquare of $abc$ is $a^2b^2c^2$, the cube is $a^3b^3c^3$, the $m$th power $a^mb^mc^m$.

§ 41. The raiſing of quantities to any power is called *Involution*; and *any ſimple quantity is involved by multiplying the exponent by that of the power required*, as in the preceding Examples. *The coefficient muſt alſo be raiſed to the ſame power* by continual multiplication of itſelf by itſelf, as often as unit is contained in the exponent of the power required. Thus the cube of $3ab$ is $3 \times 3 \times 3 \times a^3b^3 = 27a^3b^3$.

As to the Signs, *When the quantity to be involved is poſitive, it is obvious that all its powers muſt be poſitive.* And *when the quantity to be involved is negative, yet all its powers whoſe exponents are even numbers muſt be poſitive*, for any number of multiplications of a negative, if the number is even, gives a poſitive; ſince $- \times - = +$, therefore $- \times - \times - \times - = + \times + = +$; and $- \times - \times - \times - \times - \times - = + \times + \times + = +$.

The power then only can be negative when its exponent is an odd number, though the quantity to be involved be negative. The powers of $-a$ are $-a$, $+a^2$, $-a^3$, $+a^4$, $-a^5$, &c.

*&c.* Thoſe whoſe exponents are 2, 4, 6, *&c.* are poſitive; but thoſe whoſe exponents are 1, 3, 5, *&c.* are negative.

§ 42. The involution of *compound* quantities is a more difficult operation. The powers of any *binomial* $a+b$ are found by continual multiplication of it by itſelf as follows.

$a+b$ = Root.

$$\begin{array}{r} \times\ a+b \\ \hline a^2+ab \\ +\ ab+b^2 \\ \hline a^2+2ab+b^2 = \text{the Square or 2d Power.} \end{array}$$

$$\begin{array}{r} \times\ a+b \\ \hline a^3+2a^2b+ab^2 \\ +\ a^2b+2ab^2+b^3 \\ \hline a^3+3a^2b+3ab^2+b^3 = \text{Cube or 3d Power.} \end{array}$$

$$\begin{array}{r} \times\ a+b \\ \hline a^4+3a^3b+3a^2b^2+ab^3 \\ +\ a^3b+3a^2b^2+3ab^3+b^4 \\ \hline a^4+4a^3b+6a^2b^2+4ab^3+b^4 = \text{Biquadrate or 4th Power.} \end{array}$$

$$\begin{array}{r} \times\ a+b \\ \hline a^5+4a^4b+6a^3b^2+4a^2b^3+ab^4 \\ +\ a^4b+4a^3b^2+6a^2b^3+4ab^4+b^5 \\ \hline a^5+5a^4b+10a^3b^2+10a^2b^3+5ab^4+b^5 = \text{5th Power.} \end{array}$$

$$\begin{array}{r} \times\ a+b \\ \hline a^6+5a^5b+10a^4b^2+10a^3b^3+5a^2b^4+ab^5 \\ +\ a^5b+5a^4b^2+10a^3b^3+10a^2b^4+5ab^5+b^6 \\ \hline a^6+6a^5b+15a^4b^2+20a^3b^3+15a^2b^4+6ab^5+b^6 = \text{6th Power, \&c.} \end{array}$$

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lution of *compound* quantities
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itself as follows.

$$\begin{array}{r} a+b=\text{Root.} \\ \times\ a+b \\ \hline a^2+ab \\ +\ ab+b^2 \\ \hline a^2+2ab+b^2=\text{the Square or 2d Power.} \\ \times\ a+b \\ \hline a^3+2a^2b+ab^2 \\ +\ a^2b+2ab^2+b^3 \\ \hline a^3+3a^2b+3ab^2+b^3=\text{Cube or 3d Power.} \\ \times\ a+b \\ \hline a^4+3a^3b+3a^2b^2+ab^3 \\ +\ a^3b+3a^2b^2+3ab^3+b^4 \end{array}$$

§ 43.



§ 43. If the powers of $a-b$ are required, they will be found the same as the preceding, only the terms in which the exponent of $b$ is an odd number will be found negative; "because an odd number of multiplications of a negative produces a negative." Thus the cube of $a-b$ will be found to be $a^3-3a^2b+3ab^2-b^3$: where the 2d and 4th terms are negative, the exponent of $b$ being an odd number in these terms. In general, "The terms of any power of $a-b$ are positive and negative by turns."

§ 44. It is to be observed, That "in the first term of any power of $a \mp b$, the quantity $a$ has the exponent of the power required, that in the following terms, the exponent of $a$ decrease gradually by the same difference (*viz.* unit) and that in the last terms it is never found. The powers of $b$ are in the contrary order; it is not found in the first term, but its exponent in the second term is unit, in the third term its exponent is 2; and thus its exponent increases, till in the last term it becomes equal to the exponent of the power required."

As the exponents of $a$ thus decrease, and at the same time those of $b$ increase, "the sum of their exponents is always the same, and is equal to the exponent of the power required." Thus in the 6th power of $a+b$, viz. $a^6+6a^5b+15a^4b^2+20a^3b^3+15a^2b^4+6ab^5+b^6$,

the exponents of $a$ decreaſe in this order, 6, 5, 4, 3, 2, 1, 0; and thoſe of $b$ increaſe in the contrary order, 0, 1, 2, 3, 4, 5, 6. And the ſum of their exponents in any term is always 6.

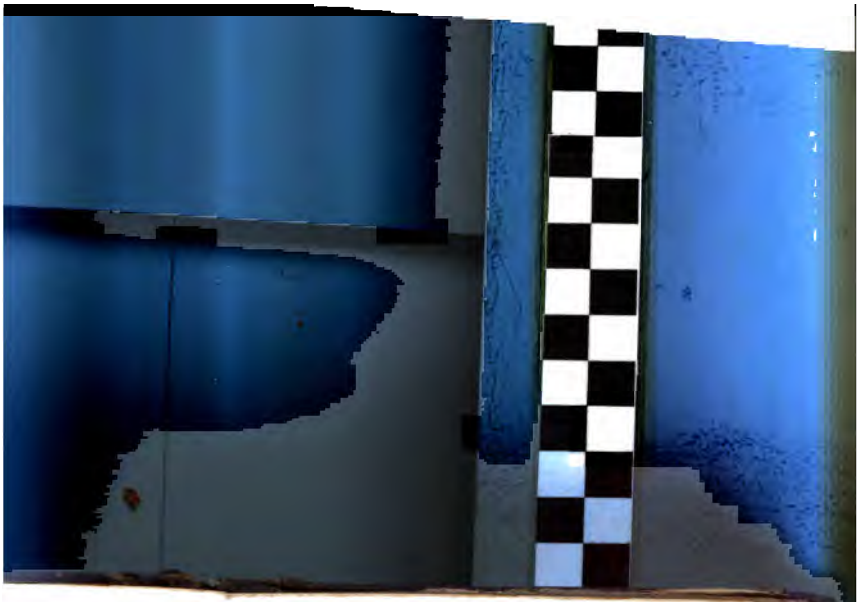
§ 45. To find their coefficient of any term, the coefficient of the precedent term being known; you are to "divide the coefficient of the preceding term by the exponent of $b$ in the given term, and to multiply the quotient by the exponent of $a$ in the ſame term, increaſed by unit. Thus to find the coefficients of the terms of the 6th power of $a+b$, you find the terms are

$$a^6,\ a^5b,\ a^4b^2,\ a^3b^3,\ a^2b^4,\ ab^5,\ b^6;$$

and you know the coefficient of the firſt term is unit; therefore, according to the rule, the coefficient of the 2d term will be $\frac{1}{1}\times\overline{5+1}=6$; that of the 3d term will be $\frac{6}{2}\times\overline{4+1}=3\times5=15$; that of the 4th term will be $\frac{15}{3}\times\overline{3+1}=5\times4=20$; and thoſe of the following will be 15, 6, 1, agreeable to the preceding Table.

§ 46. In general, if $a+b$ is to be raiſed to any power $m$, the terms, without their coefficients, will be, $a^m$, $a^{m-1}b$, $a^{m-2}b^2$, $a^{m-3}b^3$, $a^{m-4}b^4$, $a^{m-5}b^5$, *&c.* continued till the exponent of $b$ becomes equal to $m$.

The





decreaſe in this order, and thoſe of $b$ increaſe or, 0, 1, 2, 3, 4, 5, 6. exponents in any term is

r coefficient of any term, e precedent term being divide the coefficient of the exponent of $b$ in the ltiply the quotient by the ame term, increaſed by the coefficients of the r of $a+b$, you find the

$a^5b^1$, $a^4b^2$, $ab^5$, $b^6$;
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$\frac{6}{2}\times\overline{+1}=3\times5=15$;
$\frac{15}{3}\times\overline{3+1}=5\times4=20$;
ing will be 15, 6, 1, g Table.

$+b$ is to be raiſed to without their coeffi-
$^{m-2}b^2$, $a^{m-3}b^3$, $a^{m-4}b^4$,
ll the exponent of $b$

The



The coefficients of the reſpective terms, according to the laſt rule, will be

$1, m, m\times\frac{m-1}{2}, m\times\frac{m-1}{2}\times\frac{m-2}{3}, m\times\frac{m-1}{2}\times\frac{m-2}{3}\times\frac{m-3}{4}, m\times\frac{m-1}{2}\times\frac{m-2}{3}\times\frac{m-3}{4}\times\frac{m-4}{5}$, &c. continued until you have one coefficient more than there are units in $m$.

It follows therefore by theſe laſt rules, that $\overline{a+b}^m = a^m + ma^{m-1}b + m\times\frac{m-1}{2}\times a^{m-2}b^2 + m\times\frac{m-1}{2}\times\frac{m-2}{3}\times a^{m-3}b^3 + m\times\frac{m-1}{2}\times\frac{m-2}{3}\times\frac{m-3}{4}\times a^{m-4}b^4 +$, &c. which is the general *Theorem* for raiſing a quantity conſiſting of two terms to any power $m$.

§ 47. If a quantity conſiſting of three, or more terms is to be involved, "you may diſtinguiſh it into two parts, conſidering it as a binomial, and raiſe it to any power by the preceding rules; and then by the ſame rules you may ſubſtitute inſtead of the powers of theſe compound parts their values."

Thus $\overline{a+b+c}^2 = \overline{\overline{a+b}+c}^2 = \overline{a+b}^2 + 2c\times\overline{a+b}+c^2 = a^2+2ab+b^2+2ac+2bc+c^2$.

And $\overline{a+b+c}^3 = \overline{a+b}^3 + 3c\times\overline{a+b}^2 + 3c^2\times\overline{a+b}+c^3 = a^3+3a^2b+3ab^2+b^3+3a^2c+6abc+3b^2c+3ac^2+3bc^2+c^3$.

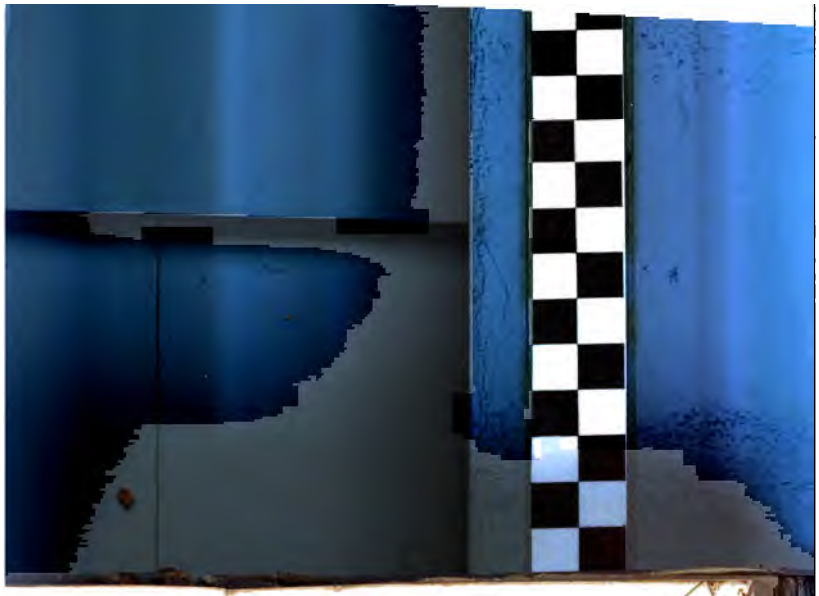
In these examples, $a + b + c$ is considered as composed of the compound part $a + b$ and the simple part $c$; and then the powers of $a + b$ are formed by the preceding rules, and substituted for $\overline{a+b}^1$ and $\overline{a+b}^2$.

## CHAP. VIII.

### Of EVOLUTION.

§ 48. THE reverse of Involution, or the resolving of powers into their roots is called *Evolution*. The roots of single quantities are easily extracted *by dividing their exponents by the number that denominates the root required*. Thus the square root of $a^8$ is $a^{\frac{8}{2}} = a^4$; and the square root of $a^4b^6c^2$ is $a^2b^3c$. The cube root of $a^6b^3$ is $a^{\frac{6}{3}}b^{\frac{3}{3}} = a^2b$; and the cube root of $x^9y^6z^{12}$ is $x^3y^2z^4$. The ground of this rule is obvious from the rule for Involution, The powers of any root are found by multiplying its exponent by the index that denominates the power; and therefore, when any power is given, the root must be found by dividing the exponent of the given power by the number that denominates the kind of root that is required.

§ 49.





ples, $a+b+c$ is conſidered
be compound part $a+b$ and
$c$; and then the powers of
by the preceding rules, and
$\overline{a+b}^2$ and $\overline{a+b}^3$.

## AP. VIII.

### OLUTION.

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ire root of $a^3$ is $a^{\frac{3}{2}}=a^1$;
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§ 49.



§ 49. It appears from what was ſaid of Involution, that "*any power that has a poſitive ſign may have either a poſitive or negative root, if the root is denominated by any even number.*" Thus the ſquare root of $+a^2$ may be $+a$ or $-a$, becauſe $+a\times+a$ or $-a\times-a$ gives $+a^2$ for the product.

But if a power have a negative ſign, "*no root of it denominated by an even number can be aſſigned,*" ſince there is no quantity that multiplied into itſelf an even number of times can give a negative product. Thus the ſquare root of $-a^2$ cannot be aſſigned, and is what we call an "*impoſſible* or *imaginary* quantity.

But if the root to be extracted is denominated by an *odd* number, *then ſhall the ſign of the root be the ſame as the ſign of the given number whoſe root is required.* Thus the cube root of $-a^3$ is $-a$, and the cube root of $a^6b^3$ is $-a^2b$.

§ 50. If the number that denominates the root required is a diviſor of the exponent of the given power, then ſhall the root be only a "*lower power of the ſame quantity.*" As the cube root of $a^{12}$ is $a^4$, the number 3 that denominates the cube root being a diviſor of 12.

But if the number that denominates what ſort of root is required is not a diviſor of the exponent of the given power, "*then the root required ſhall have a fraction for its exponent.*" Thus

Thus the ſquare root of $a^1$ is $a^{\frac{1}{2}}$; the cube root of $a^1$ is $a^{\frac{1}{3}}$, and the ſquare root of $a$ itſelf is $a^{\frac{1}{1}}$.

Theſe powers that have fractional exponents are called "*Imperfect powers* or *ſurds*;" and are otherwiſe expreſſed by placing the given power within the radical ſign $\sqrt{\ }$, and placing above the radical ſign the number that denominates what kind of root is required. Thus $a^{\frac{1}{2}} = \sqrt[2]{a^1}$; $a^{\frac{2}{3}} = \sqrt[3]{a^2}$; and $a^{\frac{m}{n}} = \sqrt[n]{a^m}$. In numbers the ſquare root of 2 is expreſſed by $\sqrt[2]{2}$, and the cube root of 4 by $\sqrt[3]{4}$.

§ 51. Theſe imperfect powers or ſurds are "*multiplied and divided*, as other powers, *by adding and ſubtracting their exponents.*" Thus $a^{\frac{1}{2}} \times a^{\frac{1}{2}} = a^{\frac{2}{2}} = a^1$; $a^{\frac{3}{7}} \times a^{\frac{4}{7}} = a^{\frac{3+4}{7}} = a^{\frac{17}{7}} = \sqrt[7]{a^{17}}$; and $\frac{a^{\frac{7}{2}}}{a^{\frac{3}{2}}} = a^{\frac{7-3}{2}} = a^{\frac{4}{2}} = a^2$.

They are *involved* likewiſe and *evolved* after the ſame manner as perfect powers. Thus the ſquare of $a^{\frac{1}{2}}$ is $a^{2\times\frac{1}{2}} = a^1$; the cube of $a^{\frac{2}{7}}$ is $a^{3\times\frac{2}{7}} = a^{\frac{6}{7}}$. The ſquare root of $a^{\frac{2}{7}}$ is $a^{\frac{2}{2\times 7}} = a^{\frac{1}{7}}$, the cube root of $a^{\frac{3}{7}}$ is $a^{\frac{3}{3\times 7}}$. But we ſhall have occaſion to treat more fully of Surds hereafter.

§ 52. The ſquare root of any compound quantity, as $a^2 + 2ab + b^2$ is diſcovered after this

this manner. "*First, take care to dispose the terms according to the dimensions of the alphabet, as in division; then find the square root of the first term aa, which gives a for the first member of the root. Then subtract its square from the proposed quantity, and divide the first term of the remainder* ($2ab+b^2$) *by the double of that member, viz.* $2a$, *and the quotient b is the second member of the root. Add this second member to the double of the first, and multiply their sum* ($2a+b$) *by the second member b, and subtract the product* ($2ab+b^2$) *from the foresaid remainder* ($2ab+b^2$) *and if nothing remains, then the square root is obtained*; and in this example it is found to be $a+b$.

The manner of the operation is thus,

$$\begin{array}{l|l} a^2+2ab+b^2 & a+b \\ \hline a^2 & \\ \hline 2a+b \times b & 2ab+b^2 \\ & 2ab+b^2 \\ \hline & 0 \quad 0 \end{array}$$

*But if there had been a remainder, you must have divided it by the double of the sum of the two parts already found, and the quotient would have given the third member of the root.*

Thus if the quantity proposed had been $a^2+2ab+2ac+b^2+2bc+c^2$, after proceeding as above you would have found the remainder

$2ac$

$2ac + 2bc + c^2$, which divided by $2a + 2b$ gives $c$ to be annexed to $a + b$ as the 3d member of the root. Then adding $c$ to $2a + 2b$ and multiplying their ſum $2a + 2b + c$ by $c$, ſubtract the product $2ac + 2bc + c^2$ from the foreſaid remainder; and ſince nothing now remains, you conclude that $a + b + c$ is the ſquare root required.

The operation is thus;

$$\begin{array}{l} a^2+2ab+2ac+b^2+2bc+c^2 \,(a+b+c \\ a^2 \\ \hline 2a+b \,\big\backslash\, 2ab+2ac+b^2+2bc+c^2 \\ \quad \times b \,\big)\, 2ab \qquad\quad +b^2 \\ \hline 2a+2b+c \,\big\backslash\, 2ac+2bc+c^2 \\ \quad \times c \,\big)\, 2ac+2bc+c^2 \\ \hline \quad 0 \quad 0 \quad 0 \end{array}$$

Another Example.

$$\begin{array}{l} xx-ax+\frac{1}{4}aa \,(x-\frac{1}{2}a \\ xx \\ \hline 2x-\frac{1}{2}a \,\big)\, -ax+\frac{1}{4}aa \\ \quad \times -\frac{1}{2}a \,\big)\, -ax+\frac{1}{4}aa \\ \hline \quad 0 \quad 0 \end{array}$$

The ſquare root of any number is found out after the ſame manner. If it is a number under 100, its neareſt ſquare root is found by the following Table; by which alſo its cube root is found

found if it be under 1000, and its biquadrate if it be under 10000.

| The Root | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Square | 1 | 4 | 9 | 16 | 25 | 36 | 49 | 64 | 81 |
| Cube | 1 | 8 | 27 | 64 | 125 | 216 | 343 | 512 | 729 |
| Biquad. | 1 | 16 | 81 | 256 | 625 | 1296 | 2401 | 4096 | 6561 |

But if it is a number above 100, then its ſquare root will conſiſt of two or more figures, which muſt be found by different operations by the following

## RULE.

§ 53. *Place a point above the number that is in the place of units, paſs the place of tens, and place again a point over that of hundreds, and go on towards the left hand, placing a point over every 2d figure; and by theſe points the number will be diſtinguiſhed into as many parts as there are figures in the root. Then find the ſquare root of the firſt part, and it will give the firſt figure of the root; ſubtract its ſquare from that part, and annex the ſecond part of the given number to the remainder. Then divide this new number (neglecting its laſt figure) by the double of the firſt figure of the root, annex the quotient to that double, and multiply the number thence ariſing by the ſaid quotient, and if the product is leſs than your dividend, or equal to it, that quotient ſhall be the ſecond figure of the root. But if the product is greater than the dividend, you muſt take a leſs number for the ſecond*

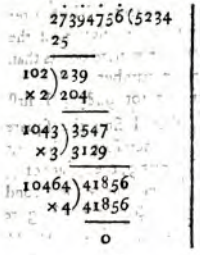
*figure*

*figure of the root than that quotient.* Much after the ſame manner may the other figures of the quotient be found, if there are more points than two places over the given number.

To find the ſquare root of 99856, I firſt point it thus $\dot{9}9\dot{8}5\dot{6}$, then I find the ſquare root of 9 to be 3, which therefore is the firſt figure of the root; I ſubtract 9, the ſquare of 3, from 9, and to the remainder I annex the ſecond part 98, and I divide (neglecting the laſt figure 8) by the double of 3, or 6, and I place the quotient after 6, and then multiply 61 by 1, and ſubtract the product 61 from 98. Then to the remainder (37) I annex the laſt part of the propoſed number (56) and dividing 3756 (neglecting the laſt figure 6) by the double of 31, that is by 62, I place the quotient after, and multiplying 626 by the quotient 6, I find the product to be 3756, which ſubtracted from the dividend and leaving no remainder, the exact root muſt be 316.

EXAMPLES.

$$
\begin{array}{r}
\dot{9}9\dot{8}5\dot{6}\,(316 \\
9 \\
\hline
61\,)\,98 \\
\times 1\,)\,61 \\
\hline
626\,)\,3756 \\
\times 6\,)\,3756 \\
\hline
0
\end{array}
$$



```
 27394756 (5234        529 (23
   25                    4
 102) 239              43) 129
 ×2)  204              ×3) 129
1043) 3547                 0
 ×3)  3129
10464) 41856
 ×4)  41856
        0
```

§ 54. In general, to extract any root out of any given quantity, "*First range that quantity according to the dimensions of its letters, and extract the said root out of the first term, and that shall be the first member of the first root required. Then raise this root to a dimension lower by unit than the number that denominates the root required, and multiply the power that arises by that number itself; divide the second term of the given quantity by the product, and the quotient shall give the second member of the root required.*"

Thus to extract the root of the 5th power out of $a^5 + 5a^4b + 10a^3b^2 + 10a^2b^3 + 5ab^4 + b^5$, I find that the root of the 5th power out of $a^5$ gives $a$, which I raise to the 4th power, and multiplying by 5, the product is $5a^4$; then dividing the second term of the given quantity $5a^4b$ by $5a^4$, I find $b$ to be the second member; and

and raiſing $a+b$ to the 5th power and ſubtracting it, there being no remainder, I conclude that $a+b$ is the root required. If the root has three members, the third is found after the ſame manner from the firſt two conſidered as one member, as the ſecond member was found from the firſt; which may be eaſily underſtood from what was ſaid of extracting the ſquare root.

§ 55. In extracting roots it will often happen that the exact root cannot be found in finite terms; thus the ſquare root of $a^2+x^2$ is found to be

$$a+\frac{x^2}{2a}-\frac{x^4}{8a^3}+\frac{x^6}{16a^5}-\frac{5x^8}{128a^7}+, \&c.$$

The operation is thus;

$$\begin{array}{l} a^2+x^2\,(a+\frac{x^2}{2a}-\frac{x^4}{8a^3}+\frac{x^6}{16a^5}-, \&c. \\ \quad a^2 \\ \hline 2a+\frac{x^2}{2a})^{*}+x^2 \\ \quad \times\frac{x^2}{2a})=x^2+\frac{x^4}{4a^2} \\ \hline 2a+\frac{x^2}{a}-\frac{x^4}{8a^3})-\frac{x^4}{4a^2} \\ \quad \times-\frac{x^4}{8a^3})=-\frac{x^4}{4a^2}-\frac{x^6}{8a^4}+\frac{x^8}{64a^6} \\ \hline \qquad\qquad +\frac{x^6}{8a^4}-\frac{x^8}{64a^6} \\ \qquad\qquad \&c. \end{array}$$

After

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no remainder, I conclude that
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are root of $a^2+x^2$ is found

$\frac{x^6}{16a^2}-\frac{5x^8}{128a^2}+$, &c.
ration is thus;
$a+\frac{x^2}{2a}-\frac{x^4}{8a^3}+\frac{x^6}{16a^5}-$, &c.

$\frac{x^4}{4a^2}-\frac{x^6}{8a^4}+\frac{x^8}{64a^6}$
$+\frac{x^6}{8a^4}-\frac{x^8}{64a^6}$
&c.

After



After the ſame manner, the cube root of $a^3+x^3$ will be found to be

$$a+\frac{x^3}{3a^2}-\frac{x^6}{9a^5}+\frac{5x^9}{81a^8}-\frac{10x^{12}}{243a^{11}}+, \&c.$$

§ 56. "The general Theorem which we gave for the Involution of binomials will ſerve alſo for their Evolution;" becauſe to extract any root of a given quantity is the ſame thing as to raiſe that quantity to a power whoſe exponent is a fraction that has unity for its numerator, and the number that expreſſes what kind of root is to be extracted for its denominator. Thus, to extract the ſquare root of $a+b$, is to raiſe $a+b$ to a power whoſe exponent is $\frac{1}{2}$: Now ſince $\overline{a+b}^m = a^m + m\times a^{m-1}b + m\times\frac{m-1}{2}a^{m-2}b^2+m\times\frac{m-1}{2}\times\frac{m-2}{3}\times a^{m-3}b^3$, &c.

Suppoſing $m=\frac{1}{2}$, you will find

$\overline{a+b}^{\frac{1}{2}} = a^{\frac{1}{2}}+\frac{1}{2}\times a^{-\frac{1}{2}}b+\frac{1}{2}\times-\frac{1}{4}\times a^{-\frac{3}{2}}b^2+\frac{1}{2}\times-\frac{1}{4}\times-\frac{3}{4}a^{-\frac{5}{2}}b^3$, &c. $= a^{\frac{1}{2}}+\frac{b}{2a^{\frac{1}{2}}}-\frac{b^2}{8a^{\frac{3}{2}}}+\frac{b^3}{16a^{\frac{5}{2}}}-$, &c. And after this manner you will find that

$\overline{a^2+x^2}^{\frac{1}{2}} = a+\frac{x^2}{2a}-\frac{x^4}{8a^3}+\frac{x^6}{16a^5}-$, &c. as before.

§ 57. The roots of numbers are to be extracted as thoſe of algebraic quantities. "*Place a point over the units, and then place points over*

*every third, fourth or fifth figure towards the left hand, according as it is the root of the cube, of the 4th or 5th power that is required; and if there be any decimals annexed to the number, point them after the same manner, proceeding from the place of units towards the right hand. By this means the number will be divided into so many periods as there are figures in the root required. Then enquire which is the greatest cube, biquadrate, or 5th power in the first period, and the root of that power will give the first figure of the root required. Subtract the greatest cube, biquadrate, or 5th power from the first period, and to the remainder annex the first figure of your second period, which shall give your dividend.*

*Raise the first figure already found to a power less by unit than the power whose root is sought, that is, to the 2d, 3d, or 4th power, according as it is the cube root, the root of the 4th, or the root of the 5th power that is required, and multiply that power by the index of the cube, 4th or 5th power, and divide the dividend by this product, so shall the quotient be the second figure of the root required.*

*Raise the part already found of the root, to the power whose root is required, and if that power be found less than the two first periods of the given number, the second figure of the root is right. But if it be found greater, you must diminish the second figure of the root till that power*

*th or fifth figure towards the*
*g as it is the root of the cube,*
*power that is required; and if*
*mals annexed to the number,*
*same manner, proceeding from*
*wards the right hand. By this*
*will be divided into ſo many pe-*
*figures in the root required.*
*is the greateſt cube, biqua-*
*in the firſt period, and the root*
*rive the firſt figure of the root*
*be greateſt cube, biquadrate,*
*firſt period, and to the re-*
*figure of your ſecond period,*
*vidend.*

*already found to a power*
*wer whoſe root is ſought,*
*or 4th power, according*
*the root of the 4th, or the*
*that is required, and mul-*
*ndex of the cube, 4th or*
*e dividend by this produ&t,*
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*required, and if that*
*the two firſt periods of*
*nd figure of the root is*
*t greater, you muſt di-*
*the root till that power*
*be*



*be found equal to or leſs than thoſe periods of the given number. Subtract it, and to the remainder annex the next period; and proceed till you have gone through the whole given number, finding the 3d figure by means of the two firſt, as you found the ſecond by the firſt; and afterwards finding the 4th figure (if there be a 4th period) after the ſame manner from the three firſt.*"

Thus to find the cube root of 13824; point it $1\dot{3}8\dot{2}4$; find the greateſt cube in 13, *viz.* 8, whoſe cube root 2 is the firſt figure of the root required. Subtract 8 from 13, and to the remainder 5 annex 8 the firſt figure of the ſecond period; divide 58 by triple the ſquare of 2, *viz.* 12. and the quotient is 4, which is the ſecond figure of the root required, ſince the cube of 24 gives 13824, the number propoſed. After the ſame manner the cube root of 133120$\dot{5}\dot{3}$ is found to be 237.

## OPERATION.

$1\dot{3}8\dot{2}4$ (24
Subtr. $8 = 2\times2\times2$

$3\times4=12)\ 58$ (4
Subtract $24\times24\times24=13824$

Rem. 0

$$\begin{array}{r} 13312053\ (237 \\ 8 = 2\times2\times2 \\ \hline 12)\ 53\ (4 \text{ or } 3 \\ \text{Subtract } 12167 = 23\times23\times23 \\ \hline 3\times23\times23 = 1587)\ 11450\ (7 \\ \text{Subtract } 13312053 = 237\times237\times237 \\ \hline \text{Remain.} \quad 0 \end{array}$$

In extracting of roots, after you have gone through the number proposed, if there is a remainder, you may continue the operation by adding periods of cyphers to that remainder, and find the true root in decimals to any degree of exactness.

## CHAP. IX.

### Of PROPORTION.

§ 58. WHEN quantities of the same kind are compared, it may be considered either how much the one is greater than the other, and what is their *difference*; or, it may be considered how many times the one is contained in the other; or, more generally, what





13312053 (237
8=2×2×2

) 53 (4 or) 3
12167=23×23×23

) 11450 (7
13312053=237×237×237

0

roots, after you have gone
r propoſed, if there is a
continue the operation by
cyphers to that remainder,
in decimals to any degree

P. IX.

ORTION.

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ne one is greater than
eir *difference*; or, it
any times the one is
or, more generally,
what



what is their *quotient*. The firſt relation of quantities is expreſſed by their *Arithmetical ratio*; the ſecond by their *Geometrical ratio*. That term whoſe ratio is enquired into is called the *antecedent*, and that with which it is compared is called the *conſequent*.

§ 59. When of four quantities the difference betwixt the firſt and ſecond is equal to the difference betwixt the third and fourth, thoſe quantities are called *Arithmetical proportionals*; as the numbers 3, 7, 12, 16. And the quantities, $a$, $a+b$, $c$, $c+b$. But quantities form a *ſeries* in arithmetical proportion, when they "*increaſe or decreaſe by the ſame conſtant difference.*" As theſe, $a$, $a+b$, $a+2b$, $a+3b$, $a+4b$, &c. $x$, $x-b$, $x-2b$, &c. or the numbers, 1, 2, 3, 4, 5, &c. and 10, 7, 4, 1, $-2$, $-5$, $-8$, &c.

§ 60. In four quantities *arithmetically proportional*, "*the ſum of the extremes is equal to the ſum of the mean terms.*" Thus $a$, $a+b$, $c$, $c+b$, are arithmetical proportionals, and the ſum of the extremes $(a+c+b)$ is equal to the ſum of the mean terms $(a+b+c)$. Hence, to find the fourth quantity arithmetically proportional to any three given quantities; "Add the ſecond and third, and from their ſum ſubtract the firſt term, the remainder ſhall give the fourth arithmetical proportional required."

§ 61. In a *series* of arithmetical proportionals "*the sum of the first and last term is equal to the sum of any two terms equally distant from the extremes.*" If the first terms are $a$, $a+b$, $a+2b$, &c. and the last term $x$, the last term but one will be $x-b$, the last but two $x-2b$, the last but three $x-3b$, &c. So that the first half of the terms, having those that are equally distant from the last term set under them, will stand thus;

$$\begin{array}{l} a,\ a+b,\ a+2b,\ a+3b,\ a+4b,\ \&c. \\ x,\ x-b,\ x-2b,\ x-3b,\ x-4b, \end{array}$$

$$a+x,\ a+x,\ a+x,\ a+x,\ a+x,\ \&c.$$

And it is plain that if each term be added to the term above it, the sum will be $a+x$ equal to the sum of the first term $a$ and the last term $x$. From which it is plain, that "*the sum of all the terms of an arithmetical progression is equal to the sum of the first and last taken half as often as there are terms,*" that is, the sum of an arithmetical progression is equal to the sum of the first and last terms multiplied by half the number of terms. Thus in the preceding series, if $n$ be the number of terms, the sum of all the terms will be $\overline{a+x} \times \frac{n}{2}$.

§ 62. The common difference of the terms being $b$, and $b$ not being found in the first term, it is plain that "its coefficient in any term

of arithmetical proportionals
*first and last term is equal to*
*terms equally distant from the*
e first terms are $a$, $a+b$,
e last term $x$, the last term
$-b$, the last but two $x-2b$,
$-3b$, &c. So that the first
aving those that are equally
t term set under them, will

$b$, $a+3b$, $a+4b$, &c.
$x-3b$, $x-4b$,

$+x$, $a+x$, $a+x$, &c.

if each term be added to
e sum will be $a+x$ equal
term $a$ and the last term
plain, that "*the sum of*
*bmetical progression is equal*
*id last taken half as often*
*it is, the sum of an arith-*
*qual to the sum of the*
*iplied by half the num-*
the preceding series, if
is, the sum of all the

difference of the terms
ing found in the first
"its coefficient in any
term



term will be equal to the number of terms that precede that term." Therefore in the last term $x$ you must have $\overline{n-1} \times b$, so that $x$ must be equal to $a+\overline{n-1} \times b$. And the sum of all the terms being $\overline{a+x} \times \frac{n}{2}$, *it will also be equal to* $\frac{2an+n^2b-nb}{2}$, *or to* $a+\frac{nb-b}{2} \times n$. Thus for example, the series $1+2+3+4+5$, &c. continued to a hundred, must be equal to $\frac{2\times 100+10000-100}{2} = 5050$.

§ 63. If a series have (o) nothing for its first term, then "*its sum shall be equal to half the product of the last term multiplied by the number of terms.*" For then, $a$ being $=0$, the sum of the terms, which is in general $\overline{a+x} \times \frac{n}{2}$, will in this case be $\frac{nx}{2}$. From which it is evident, that "the sum of any number of arithmetical proportionals beginning from nothing, is equal to half the sum of as many terms equal to the greatest term.

Thus $0+1+2+3+4+5+6+7+8+9 = \frac{9+9+9+9+9+9+9+9+9+9}{2} = \frac{10\times 9}{2} = 45$.

§ 64. If the four quantities the quotient of the *first* and *second* be equal to the quotient of the *third* and *fourth*, then those quantities are said to be in *Geometrical proportion*." Such are

the numbers 2, 6, 4, 12; and the quantities *a*, *ar*, *b*, *br*; which are expreſſed after this manner;

$$2 : 6 :: 4 : 12.$$
$$a : ar :: b : br.$$

And you read them by ſaying, As 2 is to 6, ſo is 4 to 12; or as *a* is to *ar*, ſo is *b* to *br*.

In four quantities geometrically proportional, "*the product of the extremes is equal to the product of the middle terms.*" Thus $a \times br = ar \times b$. And, if it is required to find a fourth proportional to any three given quantities, "*multiply the ſecond by the third, and divide their product by the firſt, the quotient ſhall give the fourth proportional required.*" Thus, to find a fourth proportional to *a*, *ar*, and *b*, I multiply *ar* by *b*, and divide the product *arb* by the firſt term *a*, the quotient *br* is the fourth proportional required.

§ 65. In calculations it ſometimes requires a little care to place the terms in due order; for which you may obſerve the following Rule.

"*Firſt ſet down the quantity that is of the ſame kind with the quantity ſought, then conſider, from the nature of the queſtion, whether that which is given is greater or leſs than that which is ſought; if it is greater, then place the greateſt of the other two quantities on the left hand; but if it is leſs, place the leaſt of the other two quantities on the left hand, and the other on*

*the*

6, 4, 12; and the quantities
hich are expreſſed after this

: 6 :: 4 : 12.
: *ar* :: *b* : *br*.
m by ſaying, As 2 is to 6, ſo
2 is to *ar*, ſo is *b* to *br*.
s geometrically proportional,
*extremes is equal to the product*
." Thus $a \times br = ar \times b$.
d to find a fourth proportio-
en quantities, "*multiply the*
*nd divide their product by the*
*all give the fourth propor-*
ius, to find a fourth pro-
and *b*, I multiply *ar* by *b*,
luct *arb* by the firſt term
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ns it ſometimes requires a
terms in due order; for
e the following Rule.
*quantity that is of the*
*antity ſought, then con-*
*of the queſtion, whether*
*reater or leſs than that*
*greater, then place the*
*o quantities on the left*
*ce the leaſt of the other*
*and, and the other on*
*the*



*the right*," Then ſhall the terms be in due order; and you are to proceed according to the rule, multiplying the ſecond by the third, and dividing their product by the firſt.

## EXAMPLE.

*If* 30 *men do any piece of work in* 12 *days, how many men ſhall do it in* 18 *days?*

Becauſe it is a number of men that is ſought, firſt ſet down 30, the number of men that is given: I eaſily ſee that the number that is given is greater than the number that is ſought, therefore I place 18 on the left hand, and 12 on the right; and find a fourth proportional to 18, 30, 12, *viz.* $\frac{30 \times 12}{18} = 20$.

§ 66. When a ſeries of quantities increaſe by one common multiplicator, or decreaſe by one common diviſor, they are ſaid to be in "*Geometrical proportion continued.*"

As $a$, $ar$, $ar^2$, $ar^3$, $ar^4$, $ar^5$, &c. or,

$$a, \frac{a}{r}, \frac{a}{r^2}, \frac{a}{r^3}, \frac{a}{r^4}, \frac{a}{r^5}, \text{ \&c.}$$

The common multiplier or diviſor is called their "*common ratio.*"

In ſuch a ſeries, "*the product of the firſt and laſt is always equal to the product of the ſecond and laſt but one,* or *to the product of any two terms equally remote from the extremes.* In the ſeries $a$, $ar$, $ar^2$, $ar^3$, &c. if $y$ be the laſt term, then

then ſhall the four laſt terms of the ſeries be $y, \frac{y}{r}, \frac{y}{r^2}, \frac{y}{r^3}$; now it is plain that $a \times y = ar \times \frac{y}{r} = ar^2 \times \frac{y}{r^2} = ar^3 \times \frac{y}{r^3}$, &c.

§ 67. "*The ſums of a ſeries of geometrical proportionals wanting the firſt term, is equal to the ſum of all but the laſt term multiplied by the common ratio.*"

For $ar + ar^2 + ar^3$, &c. $+ \frac{y}{r^3} + \frac{y}{r^2} + \frac{y}{r} + y$
$= r \times a + ar + ar^2$, &c. $+ \frac{y}{r^3} + \frac{y}{r^2} + \frac{y}{r^1} + \frac{y}{r}$.
Therefore if $s$ be the ſum of the ſeries, $s - a$ will be equal to $\overline{s - y} \times r$; that is $s - a = sr - yr$, or $sr - s = yr - a$, and $s = \frac{yr - a}{r - 1}$*.

§ 68. Since the exponent of $r$ is always increaſing from the ſecond term, if the number of terms be $n$, in the laſt term its exponent will be $n - 1$. Therefore $y = ar^{n-1}$; and $yr = ar^{n-1+1} = ar^n$; and $s = \left(\frac{yr - a}{r - 1}\right) = \frac{ar^n - a}{r - 1}$. So that having the firſt term of the ſeries, the number of the terms, and the common ratio, you may eaſily find the ſum of all the terms.

If it is a decreaſing ſeries whoſe ſum is to be found, as of $y + \frac{y}{r} + \frac{y}{r^2} + \frac{y}{r^3}$, &c. $+ ar^2 + ar^1 + ar + a$, and the number of the terms be

* See the Rules in the following Chapter.

ſup-

…TREATISE *of* Part I.

…four laſt terms of the ſeries is

…ow it is plain that $a \times y =$

$\frac{y}{r} = ar^1 \times \frac{y}{r^3}$, &c.

*…ms of a ſeries of geometrical pro-*
*…g the firſt term, is equal to the*
*laſt term multiplied by the com-*

$\ldots r^1$, &c. $+ \frac{y}{r^3} + \frac{y}{r^2} + \frac{y}{r} + 1$

$\ldots r^3$, &c. $+ \frac{y}{r^4} + \frac{y}{r^3} + \frac{y}{r^2} + \frac{y}{r} + 1$.

…the ſum of the ſeries, $s - a$
$\ldots - y \times r$; that is $s - a =$
$r - a$, and $s = \frac{yr - a}{r - 1}$.

…ponent of $r$ is always on…
…cond term, if the number
…laſt term its exponent will
…ore $y = ar^{n-1}$; and $yr =$
$\ldots = \left(\frac{yr - a}{r - 1}\right) = \frac{ar^n - a}{r - 1}$. So
…rm of the ſeries, the num-
…l the common ratio, you
…n of all the terms.
…ſeries whoſe ſum is to be
$\ldots \frac{y}{r^2} + \frac{y}{r^3}$, &c. $+ ar^3 +$
…umber of the terms be
…e following Chapter. ſup-

ſuppoſed infinite, then ſhall $a$, the laſt term, be equal to nothing. For, becauſe $n$, and conſequently $r^{n-1}$ is infinite, $a = \frac{y}{r^{n-1}} = 0$. The ſum of ſuch a ſeries $s = \frac{yr}{r-1}$; which is a finite ſum, though the number of terms be infinite.

Thus $1 + \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16} +$, &c. $= \frac{1 \times 2}{2-1} = 2$.

and $1 + \frac{1}{3} + \frac{1}{9} + \frac{1}{27} + \frac{1}{81} +$, &c. $= \frac{1 \times 3}{3-1} = \frac{3}{2}$.

## CHAP. X.

## Of EQUATIONS that involve only one unknown Quantity.

§ 69. AN *equation* is "*a propoſition aſſerting the equality of two quantities.*" It is expreſſed moſt commonly by ſetting down the quantities, and placing the ſign (=) between them.

An equation gives the value of a quantity, when that quantity is alone on one ſide of the equation: and that value is known, if all thoſe that are on the other ſide are known. Thus if I find that $x = \frac{4 \times 6}{3} = 8$, I have a known value of $x$. Theſe are the laſt concluſions we are to

to ſeek in queſtions to be reſolved; and if there be only one unknown quantity in a given equation, and only one dimenſion of it, ſuch a value may always be found by the following Rules.

## RULE I.

§ 70. "*A quantity may be tranſpoſed from one ſide of the equation to the other, if you change its ſign.*"

For to take away a quantity from one ſide, and to place it with a contrary ſign on the other ſide, is to ſubtract it from both ſides; and it is certain, that "when from equal quantities you ſubtract the ſame quantity, the remainders muſt be equal."

By this Rule, when the known and unknown quantities are mixed in an equation, you may ſeparate them by bringing all the unknown to one ſide, and the known to the other ſide of the equation; as in the following Examples.

Suppoſe $5x+50=4x+56$,
By tranſpoſit. $5x-4x=56-50$, or, $x=6$.
And if $2x+a=x+b$,
$2x-x=b-a$, or, $x=b-a$.

## RULE II.

§ 71. "*Any quantity by which the unknown quantity is multiplied may be taken away, if you divide all the other quantities on both ſides of the equation by it.*"

For

ons to be resolved; and if there
nown quantity in a given equa-
ie dimension of it, such a value
ound by the following Rules.

## RULE I.

*ity may be transposed from one*
*tion to the other, if you change*

way a quantity from one side,
a contrary sign on the other
it from both sides; and it
when from equal quantities
ne quantity, the remainder

n the known and unknown
l in an equation, you may
nging all the unknown to
wn to the other side of the
llowing Examples.

$=4x+56$,
$=56-50$, or, $x=6$.
$=x+b$,
$b-a$, or, $x=b-a$.

## E II.

*which the unknown quan-*
*be taken away, if you*
*ntities on both sides of*

For



For that is to divide both sides of the equation by the same quantity; and when you divide equal quantities by the same quantity, the quotients must be equal. Thus,

If $ax=b$,
then $x=\frac{b}{a}$.

And if $3x+12=27$,
by Rule 1. $3x=27-12=15$,
and by Rule 2. $x=\frac{15}{3}=5$.

Also if $ax+2ba=3cc$,
by Rule 1. $ax=3cc-2ba$,
and by Rule 2. $x=\frac{3cc}{a}-2b$.

## RULE III.

§ 72. *If the unknown quantitity is divided by any quantity, that quantity may be taken away if you multiply all the other members of the equation by it.*" Thus,

If $\frac{x}{b}=b+5$,
then shall $x=bb+5b$.

If $\frac{x}{5}+4=10$,
$x+20=50$,
and by Rule. 1. $x=50-20=30$.

If

If $\frac{4x}{3}+24=2x+6$,

$4x+72=6x+18$,

by Rule 1. $72-18=6x-4x$, or $54=2x$.

and by Rule 2. $x=\frac{54}{2}=27$.

By this Rule an equation, whereof any part is a fraction, may be reduced to an equation that ſhall be expreſſed by integers. If there are more fractions than one in the given equation, you may, by reducing them to a common denominator, and then multiplying all the other terms by that denominator, abridge the calculation thus;

If $\frac{x}{5}+\frac{x}{3}=x-7$,

then $\frac{3x+5x}{15}=x-7$,

and by this Rule $3x+5x=15x-105$,

and by Rule 1 and 2. $x=\frac{105}{7}=15$.

## RULE IV.

§ 73. "*If the member of the equation that involves the unknown quantity be a* ſurd *root, then the equation is to be reduced to another that ſhall be free from any ſurd, by bringing that member firſt to ſtand alone upon one ſide of the equation, and then taking away the radical ſign from it, and raiſing the other ſide of the equation to the power denominated by the ſurd*".

Thus

$\frac{4x}{3}+24=2x+6$,
$4x+72=6x+18$,
$72-18=6x-4x$, or $54=2x$.
$x=\frac{54}{2}=27$.

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be reduced to an equation that
ed by integers. If there are
han one in the given equation,
lucing them to a common de-
then multiplying all the other
ominator, abridge the calcula-

If $\frac{x}{5}+\frac{x}{3}=x-7$,
en $\frac{3x+5x}{15}=x-7$,
le $3x+5x=15x-105$,
2. $x=\frac{105}{7}=15$.

## JLE IV.

*ber of the equation that in-*
*m quantity be a* surd *root,*
*is to be reduced to another*
*from any surd, by bringing*
*to ſtand alone upon one ſide*
*nd then taking away the*
*and raiſing the other ſide*
*he power denominated by the*

Thus



Thus if $\sqrt{4x+16}=12$,
$4x+16=144$,
and $4x=144-16=128$,
and $x=\frac{128}{4}=32$.

If $\sqrt{ax+b^2}-c=d$,
then $\sqrt{ax+b^2}=d+c$,
$ax+b^2=d^2+2dc+c^2$,
and $x=\frac{d^2+2dc+c^2-b^2}{a}$.

If $\sqrt[3]{a^3x-b^3x}=a$,
then $a^3x-b^3x=a^3$,
and $x=\frac{a^3}{a^3-b^3}$.

## RULE V.

§ 74. "*If that ſide of the equation that contains the unknown quantity be a compleat ſquare, cube, or other power; then extract the ſquare root, cube root, or the root of that power, from both ſides of the equation, and thus the equation ſhall be reduced to one of a lower degree*".

If $x^2+6x+9=20$,
then $x+3=\pm\sqrt{20}$,
and $x=\pm\sqrt{20}-3$.

If

If $x^2+ax+\frac{a^2}{4}=b^2$,

then $x+\frac{a}{2}=\pm b^2$,

and $x=\pm b-\frac{a}{2}$.

If $x^2+14x+49=121$,
then $x+7=\pm 11$,
and $x=\pm 11-7=4$, or $-18$.

## RULE VI.

§ 75. "*A proportion may be converted into an equation, asserting the product of the extreme terms equal to the product of the mean terms; or any one of the extremes equal to the product of the means divided by the other extreme.*"

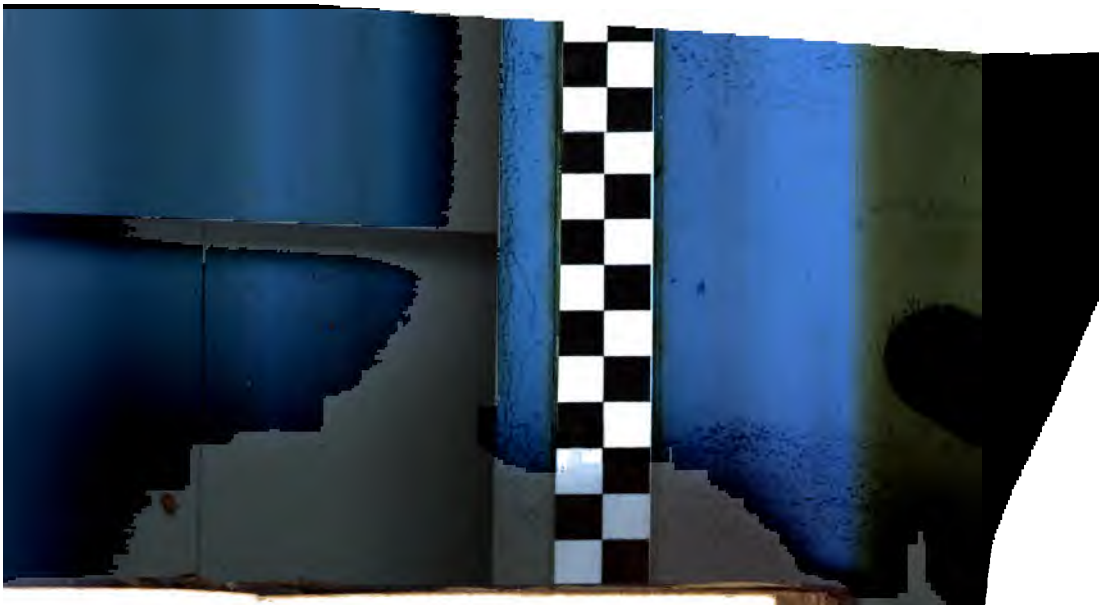
If $12-x:\frac{x}{2}::4:1$,

then $12-x=2x\ldots.3x=12\ldots.$ and $x=4$.

Or if $20-x:x::7:3$,
then $60-3x=7x\ldots.10x=60\ldots.$ and $x=6$.

## RULE VII.

§ 76. "*If any quantity be found on both sides of the equation with the same sign prefixt, it may be taken away from both:*" "*Also, if all the quantities in the equation are multiplied or divided*





If $x^2+ax+\frac{a^2}{4}=b^2$,

en $x+\frac{a}{2}=\pm b^2$,

id $x=\pm b-\frac{a}{2}$.

$x^2+14x+49=121$,
$x+7=\pm 11$,
$x=\pm 11-7=4$, or $-18$.

## RULE VI.

*ortion may be converted into a*
*·ting the product of the extrem*
*the product of the mean terms;*
*the extremes equal to the pro-*
*means divided by the other e*

$:4:1$,
$\ldots 3x=12\ldots$ and $x=4$.

$7:3$,
$\ldots 10x=60\ldots$ and $x=6$.

## JLE VII.

*ıtity be found on both sides of*
*the same sign prefixt, it may*
*om both:*" "*Also, if all the*
*equation are multiplied or*
*divided*



*divided by the same quantity, it may be struck out of them all.*" Thus,

If $3x+b=a+b\ldots 3x=a\ldots$ and $x=\frac{a}{3}$.

If $3ax+5ab=8ac..3x+5b=8c..$ and $x=\frac{8c-5b}{3}$.

If $\frac{7x}{3}+\frac{8}{3}=\frac{16}{3}\ldots 2x+8=16\ldots$ and $x=4$.

## RULE VIII.

§ 77. "*Instead of any quantity in an equation you may substitute another equal to it.*"

Thus, if $3x+y=24$,
and $y=9$;
then $3x+9=24\ldots x=\frac{24-9}{3}=5$.

If $3y+5x=120$,
and $y=5x$;
then $15x+5x(=20x)=120$,
and $x=\frac{120}{20}=6$.

The further improvements of this Rule shall be taught in the following chapter.

## CHAP. IX.

### Of the Solutions of queſtions that produce ſimple equations.

SIMPLE equations are thoſe "wherein the unknown quantity is only of one dimenſion:" In the ſolution of which we are to obſerve the following directions.

#### DIRECTION I.

§ 78. "*After forming a diſtinct idea of the queſtion propoſed, the unknown quantities are to be expreſſed by letters, and the particulars to be tranſlated from the common language into the algebraic manner of expreſſing them, that is, into ſuch equations as ſhall expreſs the relations or properties that are given of ſuch quantities.*"

Thus, if the ſum of two quantities muſt be 60, that condition is expreſſed thus, $x+y=60$.

If their difference muſt be 24, that condition gives . . . . . $x-y=24$.

If their product muſt be 1640, then $xy=1640$.

If their quotient muſt be 6, then . . . $\frac{x}{y}=6$.

If their proportion is as 3 to 2, then $x:y::3:2$, or $2x=3y$; becauſe the product of the extremes

## HAP. IX.

tions of queſtions that ſimple equations.

tions are thoſe "wherein the u- ity is only of one dimenſion:" which we are to obſerve the ns.

### ECTION I.

*ing a diſtinct idea of the qu- he unknown quantities are to it s, and the particulars to it he common language into the of expreſſing them, that is, s as ſhall expreſs the rela- that are given of ſuch quan-*

two quantities muſt be 60, expreſſed thus, $x+y=60$. ıſt be 24, that condition . . . . . $x-y=24$. be 1640, then $xy=1640$. be 6, then . . . $\frac{x}{y}=6$. s 3 to 2, then $x:y::3:2$, the product of the ex- tremes



tremes is equal to the product of the mean terms.

### DIRECTION II.

§ 79. "*After an equation is formed, if you have one unknown quantity only, then, by the Rules of the preceding Chapter, bring it to ſtand alone on one ſide, ſo as to have only known quantities on the other ſide:*" *thus you ſhall diſcover its value.*

### EXAMPLE.

*A perſon being aſked what was his age, anſwered that $\frac{1}{4}$ of his age multiplied by $\frac{1}{12}$ of his age gives a product equal to his age. Qu. what was his age?*

It appears from the queſtion, that if you call his age $x$, then ſhall . . . $\frac{3x}{4}\times\frac{x}{12}=x$,

that is . . . $\frac{3x^2}{48}=x$,

and by Rule 3. . . . $3x^2=48x$,

and by Rule 7. . . . $3x=48$,

whence by Rule 2. . . . $x=16$.

### DIRECTION III.

§ 80. "*If there are two unknown quantities, then there muſt be two equations ariſing from the conditions of the queſtion: Suppoſe the quantities $x$ and $y$; find a value of $x$ or $y$, from*

*each of the equations, and then by putting these two values equal to each other, there will arise a new equation involving one unknown quantity; which must be reduced by the Rules of the former Chapter.*"

## EXAMPLE I.

*Let the sum of two quantities be s, and their difference d. Let s and d be given, and let it be required to find the quantities themselves.* Suppose them to be $x$ and $y$, then, by the supposition,

$$\begin{array}{r} x+y=s \\ x-y=d \\ \hline \text{whence } \begin{cases} x=s-y \\ x=d+y \end{cases} \\ \text{and } d+y=s-y \\ 2y=s-d \\ y=\frac{s-d}{2} \\ \text{and } x=\frac{s+d}{2}. \end{array}$$

## EXAMPLE II.

*Let it be required to find two numbers whose sum is s, and their proportion as a to b. Let the numbers be x and y, then shall*

Suppos.

*e equations, and then by putting values equal to each other, there a new equation involving one unknown tity; which must be reduced by the former Chapter."*

XAMPLE I.

*of two quantities be s, and their et s and d be given, and let it be the quantities themselves.* Suppose *x* and *y*, then, by the sup-

$$\begin{array}{l} x+y=s \\ x-y=d \\ \hline \left\{\begin{array}{l} x=s-y \\ x=d+y \end{array}\right. \\ +y=s-y \\ 2y=s-d \\ y=\frac{s-d}{2} \\ x=\frac{s+d}{2}. \end{array}$$

MPLE II.

*d to find two numbers whose roportion as a to b. Let the hen shall*

Suppos.



Suppos. $\left\{\begin{array}{l} x+y=s \\ x:y::a:b \end{array}\right.$

$$\begin{array}{l} \hline bx=ay \\ x=\frac{ay}{b} \\ x=s-y \\ \frac{ay}{b}=s-y \\ \frac{ay}{b}+y=s \\ ay+by=bs \\ \hline a+b\times y=bs \\ y=\frac{bs}{a+b} \\ x=\frac{ay}{b}=\frac{as}{a+b}. \end{array}$$

## EXAMPLE III.

*A privateer running at the rate of 10 miles an hour, discovers a ship 18 miles off making way at the rate of 8 miles an hour: It is demanded how many miles the ship can run before she be overtaken?*

Let the number of miles the ship can run before she be overtaken be called $x$; and the number of miles the privateer must run before she come up with the ship, be $y$; then shall (by *Supp.*) .... $y=x+18$ .... and $x:y::8:10$, whence $10x=8y$ .... $x=\frac{4y}{5}$ .... and $x=y-18$.

Whence $y-18=\frac{4y}{5}$, and $y=90$, $\therefore x=y-18=72$.

To find the time, ſay, if 8 miles give 1 hour; 72 miles will give 9 hours.—Thus, 8 : 1 :: 72 : 9.

## EXAMPLE IV.

*Suppoſe the diſtance between* London *and* Edinburgh *to be* 360 *miles, and that a courier ſets out from* Edinburgh *running at the rate of* 10 *miles an hour; another ſets out at the ſame time from* London, *and runs* 8 *miles an hour. It is required to know where they will meet?* Suppoſe the courier that ſets out from *Edinburgh* runs $x$ miles, and the other $y$ miles before they meet; then ſhall

by ſuppoſ. $\begin{cases} x+y=360 \\ x:y :: 5:4 \end{cases}$

$$x=\frac{5y}{4}$$
$$x=360-y$$
$$\frac{5y}{4}=360-y$$
$$\frac{5y}{4}+y=360$$
$$9y=1440$$
$$y=\frac{1440}{9}=160$$
$$x=360-y=200.$$

## EXAMPLE V.

*Two perſons diſcourſing of their revenues, ſays* A, *if* B *would yield him a poſt he has of* 25 l. *a year,*

*year, their revenues would be equal: Says* B, *if* A *would give him a place he holds of* 22 l. per annum, *the revenue of* B *would be double that of* A. Qu. *their revenues?*

Let the revenue of *A* be called $x$, that of *B*, $y$; then,

by supp. $\begin{cases} x+25 = y-25 \\ y+22 = 2x-44 \end{cases}$

$y = x+25+25 = x+50$
$y = 2x-44-22 = 2x-66$
$2x-66 = x+50$
$x = 66+50 = 116$
$y = a+50 = 166.$

## EXAMPLE VI.

*A gentleman distributing money among some poor people, found he wanted* 10 s. *to be able to give* 5 s. *to each; therefore he gives each* 4 s. *only, and finds that he has* 5 s. *left.* Qu. *the number of shillings and poor people?*

Call the number of the poor $x$, and the number of shillings $y$; then,

by supp. $\begin{cases} 5x = y+10 \\ 4x = y-5 \end{cases}$

$y = 5x-10$
$y = 4x+5$
$5x-10 = 4x+5$
$5x-4x = 15$
$x = 15$
$y = 4x+5 = 65$

## EXAMPLE VII.

*Two merchants were copartners; the sum of their stock was* 300*l. One of their stocks continued in company* 11 *months; but the other drew out his stock in* 9 *months; when they made up their accounts they divided the gain equally.* Qu. *What was each man's stock?* Suppose the stock of the first to be $x$, and the stock of the other to be $y$; then,

by supp. $\begin{cases} x+y=300 \\ 11x=9y \end{cases}$

$$x=\frac{9y}{11}=300-y$$
$$11y+9y=3300$$
$$20y=3300$$
$$y=\frac{3300}{20}=165 \therefore x=300-y=135.$$

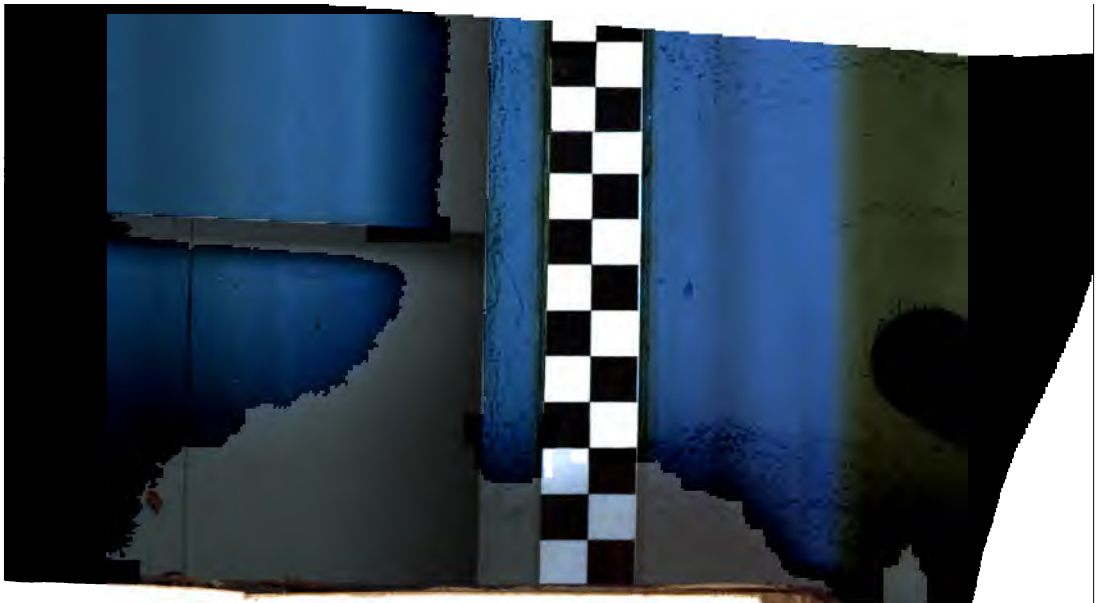
## EXAMPLE. VIII.

*There are two numbers whose sum is the* 6*th part of their product, and the greater is to the lesser as* 3 *to* 2. Qu. *What are these numbers?* Call them $x$ and $y$; then,

supp. $\begin{cases} x+y=\frac{xy}{6} \\ x:y::3:2 \end{cases}$

$$yx=6x+6y$$
$$yx-6x=6y$$
$$y-6\times x=6y$$
$$x=\frac{6y}{y-6}$$
$$x=\frac{3y}{2}, \text{ whence}*$$

$$*\ \frac{6y}{y-6}=\frac{3y}{2}$$
$$12y=3yy-18y$$
$$30y=3yy$$
$$30=3y$$
$$y=\frac{30}{3}=10$$
$$x=\frac{3\times 10}{2}=15.$$





KAMPLE VII.

*ts were copartners; the sum of their*
*One of their stocks continued in com-*
*but the other drew out his stock in*
*they made up their accounts they*
*qually. Qu. What was each man's*
the stock of the first to be *x*,
the other to be *y*; then,

$=300$
$-y$

$=300-y$

$=3300$

$=165 \ldots x=300-y=135.$

PLE. VIII.

*rs whose sum is the 6th part*
*the greater is to the lesser as*
*these numbers?* Call them

$$* \frac{6y}{y-6} = \frac{3y}{2}$$
$$12y = 3yy - 18y$$
$$30y = 3yy$$
$$30 = 3y$$
$$y = \frac{30}{3} = 10$$
$$x = \frac{3 \times 10}{2} = 15.$$

DI-



## DIRECTION IV.

§ 81. "*When in one of the given equations, the unknown quantity is of one dimension, and in the other of a higher dimension; you must find a value of the unknown quantity from that equation where it is of one dimension, and then raise that value to the power of the unknown quantity in the other equation; and by comparing it, so involved, with the value you deduce from that other equation, you shall obtain an equation that will have only one unknown quantity, and its powers.*"

That is, when you have two equations of different dimensions, if you cannot reduce the higher to the same dimension with the lower, you must raise the lower to the same dimension with the higher.

## EXAMPLE IX.

*The sum of two quantities, and the difference of their squares, being given, to find the quantities.* Suppose them to be $x$ and $y$, their sum $s$, and difference of their squares $d$. Then,

$$\begin{cases} x+y=s \\ x^2-y^2=d \end{cases}$$

$$x = s - y$$
$$x^2 = s^2 - 2sy + y^2$$
$$x^2 = d + y^2$$
$$d + y^2 = s^2 - 2sy + y^2$$
$$d = s^2 - 2sy, \text{ whence } *$$

$$* \quad 2sy = s^2 - d$$
$$y = \frac{s^2-d}{2s}$$
and $$x = \frac{s^2+d}{2s}.$$

EXAMPLE

## EXAMPLE X.

*Let the proportion of two numbers and the ſum of their ſquares be given, and let it be required to find the numbers themſelves.* Suppoſe their proportion to be the ſame as that of $a$ to $b$, and let the ſum of their ſquares be $c$; that is, let

$$\left\{\begin{array}{l} x : y :: a : b \\ x^2+y^2 = c \end{array}\right.$$

then $x = \frac{ay}{b}$,

and $x^2 = \frac{a^2y^2}{b^2}$;

but $x^2 = c - y^2$,

whence $c - y^2 = \frac{a^2y^2}{b^2}$

$$b^2y^2 + a^2y^2 = cb^2$$

$$\overline{a^2+b^2} \times y^2 = cb^2$$

$$y^2 = \frac{cb^2}{a^2+b^2}$$

$$y = \sqrt{\frac{cb^2}{a^2+b^2}}, \text{ and } x = \sqrt{\frac{ca^2}{a^2+b^2}}.$$

## EXAMPLE XI.

*Let the proportion of two numbers be that of $a$ to $b$, and the difference of their cubes be $d$.* Qu. *What are the numbers?* Then,

$x : y$

XAMPLE X.

*portion of two numbers and the ſum be given, and let it be required to them themſelves.* Suppoſe their pro- ne ſame as that of $a$ to $b$, and heir ſquares be $c$; that is, let

$: b$
$= c$

$y^2$,
$\frac{a^2y^2}{b^2}$
$= cb^2$
$= cb^2$

$\frac{}{}$
$\frac{cb^2}{}$, and $x = \sqrt{\frac{ca^2}{a^2+b^2}}$.

MPLE XI.

*of two numbers be that of rence of their cubes be d. mbers?* Then,

$x : y$



$$\begin{cases} x : y :: a : b \\ x^3 - y^3 = d \end{cases}$$

$$x = \frac{ay}{b}, \text{ and } x^3 = \frac{a^3y^3}{b^3};$$

but $x^3 = d + y^3$

whence $d + y^3 = \frac{a^3y^3}{b^3}$,

and $a^3y^3 - b^3y^3 = db^3$

$$y^3 = \frac{db^3}{a^3 - b^3}$$

$$y = \sqrt[3]{\frac{db^3}{a^3 - b^3}}$$

and $x = \sqrt[3]{\frac{da^3}{a^3 - b^3}}$.

## DIRECTION V.

§ 82. "*If there are three unknown quantities, there muſt be three equations in order to determine them, by comparing which you may, in all caſes, find two equations involving only two unknown quantities; and then, by* Direction 3, *from theſe two you may deduce an equation involving only one unknown quantity; which may be reſolved by the Rules of the laſt Chapter.*"

From three equations involving any three unknown quantities, $x$, $y$, and $z$, to deduce two equa-

equations involving only two unknown quantities, the following Rule will always ſerve.

## RULE.

"*Find three values of* x *from the three given equations*; *then, by comparing the firſt and ſecond value, you will find an equation involving only* y *and* z; *again, by comparing the firſt and third, you will find another equation involving only* y *and* z;" *and laſtly, thoſe equations are to be reſolved by* Direction 3.

## EXAMPLE XII.

Suppoſe

$$\left.\begin{array}{l} x+y+z=12 \\ x+2y+3z=20 \\ \frac{x}{3}+\frac{y}{2}+z=6 \end{array}\right\} \text{then,} \left\{ x= \left\{\begin{array}{l} 12-y-z \\ 20-2y-3z \\ 18-\frac{3y}{2}-3z \end{array}\right\} \begin{array}{l} 1\text{ſt} \\ 2\text{d} \\ 3\text{d} \end{array} \right\} \text{value.}$$

$$12-y-z=20-2y-3z$$

$$12-y-z=18-\frac{3y}{2}-3z$$

Theſe two laſt equations involve only $y$ and $z$, and are to be reſolved, by *Direction* 3, as follows.

2y—

$$\begin{cases} 2y-y+3z-z=20-12=8 \\ y+2z=8 \end{cases}$$

$$36-3y-6z=24-2y-2z$$
$$12=y+4z$$

whence $y=\begin{cases} 8-2z \ldots \text{1ſt value.} \\ 12-4z \ldots \text{2d value.} \end{cases}$

$$8-2z=12-4z$$
$$2z=12-8=4$$

and $z=2$

$$y(=8-2z)=4$$
$$x(=12-y-z=6.$$

§ 83. This method is general, and will extend to all equations that involve three unknown quantities: but there are often eaſier and ſhorter methods to deduce an equation involving one unknown quantity only; which will be beſt learned by practice.

## EXAMPLE XIII.

Suppoſing $\begin{cases} x+y+z=26 \\ x-y=4 \\ x-z=6 \end{cases}$

by addition $3x=36$

$$\begin{cases} x=\frac{36}{3}=12 \\ y=x-4=8 \\ z=x-6=6. \end{cases}$$

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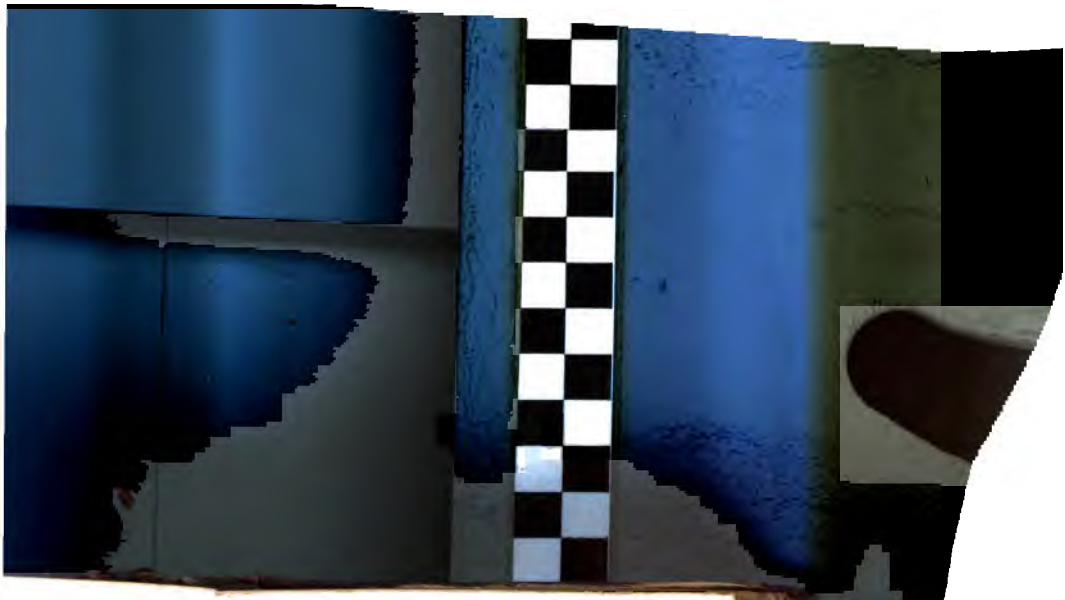
## EXAMPLE XIV.

Supposing $\begin{cases} x+y=a \\ x+z=b \\ y+z=c \end{cases}$

$$x=a-y$$
$$a-y+z=b$$
$$y+z=c$$
$$a+0+2z=b+c$$
$$2z=b+c-a$$
$$\begin{cases} z=\frac{b+c-a}{2} \\ y(=c-z)=\frac{c+a-b}{2} \\ x(=a-y)=\frac{a+b-c}{2}. \end{cases}$$

§ 84. It is obvious from the 3d and 5th Directions, in what manner you are to work if there are four, or more, unknown quantities, and four, or more, equations given. By comparing the given equations, you may always at length discover an equation involving only one unknown quantity; which, if it is a simple equation, may always be resolved by the Rules of the last Chapter. We may conclude then, that "When there are as many simple equations given as quantities required, these quantities may be discovered by the application of the preceding Rules."

§ 85.





AMPLE XIV.

$y=a$
$z=b$
$z=c$
$a-y$
$+z=b$
$+z=c$
$+2z=b+c$
$2z=b+c-a$

$$\begin{cases} z=\frac{b+c-a}{2} \\ y(=c-z)=\frac{c+a-b}{2} \\ x(=a-y)=\frac{a+b-c}{2}. \end{cases}$$

s from the 3d and 5th Di
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ore, unknown quantities,
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tions, you may always at
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which, if it is a ſimple
e reſolved by the Rules
We may conclude then,
s many ſimple equations
quired, theſe quantities
e application of the pre-

§ 85.



§ 85. "If indeed there are more quantities required than equations given, then the queſtion is not limited to determinate quantities; but is capable of an infinite number of ſolutions." And, "If there are more equations given than there are quantities required, it may be impoſſible to find the quantities that will anſwer the conditions of the queſtion;" becauſe ſome of theſe conditions may be inconſiſtent with others.

## CHAP. XII.

### Containing ſome General Theorems for the exterminating unknown Quantities in given Equations.

IN the following *Theorems*, we call thoſe coefficients of the "*ſame order*" that are prefixt to the ſame unknown quantities in the different equations. Thus, in *Theor.* 2, *a*, *d*, *g*, are of the ſame order, being the coefficients of *x*: alſo *b*, *e*, *h*, are of the ſame order, being the coefficients of *y*: and thoſe are of the ſame order that affect no unknown quantity.

But thoſe are called "*oppoſite*" coefficients that are taken each from a different equation, and

and from a different order of coefficients: As, $a$, $c$, and $d$, $b$, in the firſt Theorem; and $a$, $c$, $k$, in the ſecond; alſo, $a$, $b$, $f$; and $d$, $b$, $k$, &c.

## THEOREM I.

§ 86. Suppoſe that two equations are given, involving two unknown quantities, as

$$\begin{cases} ax + by = c \\ dx + cy = f \end{cases}$$

then ſhall $y = \frac{af - dc}{ae - db}$.

Where the numerator is the difference of the products of the oppoſite coefficients in the orders in which $y$ is not found, and the denominator is the difference of the products of the oppoſite coefficients taken from the orders that involve the two unknown quantities.

For, from the firſt equation, it is plain that

$$ax = c - by \text{ .. and } x = \frac{c - by}{a},$$

from the 2d, $dx = f - cy$ .. and $x = \frac{f - cy}{d}$,

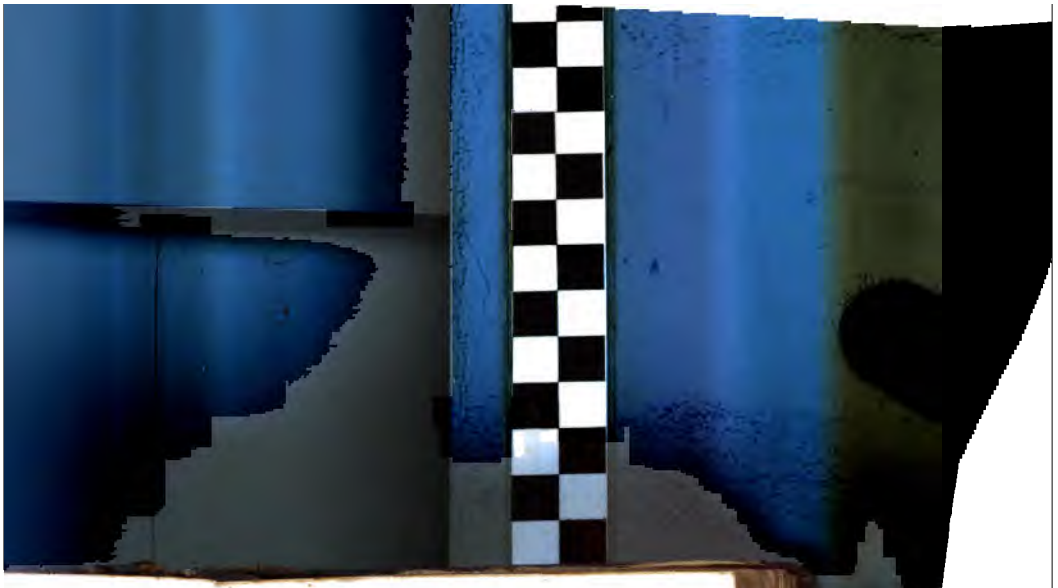
therefore $\frac{c - by}{a} = \frac{f - cy}{d}$, and $cd - dby = af - acy$;

whence $acy - dby = af - cd$,

and $y = \frac{af - cd}{ae - db}$;

after the ſame manner, $x = \frac{ce - bf}{ae - db}$.

EX-





rent order of coefficients: As,
in the first Theorem; and
fecond; alſo, $a$, $b$, $f$, and

THEOREM I.

that two equations are given,
known quantities, as

$ax + by = e$
$dx + cy = f$

$y = \frac{af - dc}{ae - db}$.

rator is the difference of the
poſite coefficients in the or-
not found, and the deno-
nce of the products of the
taken from the orders that
own quantities.

equation, it is plain that

$- by$ .. and $x = \frac{c - by}{a}$,

$- cy$ .. and $x = \frac{f - cy}{d}$,

, and $cd - dby = af - acy$;

nce $acy - dby = af - cd$,

and $y = \frac{af - cd}{ae - db}$;

$= \frac{ce - bf}{ae - db}$.

EX-



EXAMPLE I.

Supp. $\begin{cases} 5x + 7y = 100 \\ 3x + 8y = 80 \end{cases}$

then $y = \frac{5 \times 80 - 3 \times 100}{5 \times 8 - 3 \times 7} = \frac{100}{19} = 5\frac{5}{19}$

and $x = \frac{240}{19} = 12\frac{12}{19}$.

EXAMPLE II.

$\begin{cases} 4x + 8y = 90 \\ 3x - 2y = 160 \end{cases}$

$y = \frac{4 \times 160 - 3 \times 90}{4 \times -2 - 3 \times 8} = \frac{640 - 270}{-8 - 24} = \frac{370}{-32} = -11\frac{9}{16}$.

THEOREM II.

§ 87. Suppoſe now that there are three unknown quantities and three equations, then call the unknown quantities $x$, $y$, and $z$.

Thus $\begin{cases} ax + by + cz = m \\ dx + cy + fz = n \\ gx + hy + kz = p \end{cases}$

Then ſhall $z = \frac{aep - afn + dhm - dbp + gbn - gem}{aek - afh + dhc - dbk + gbf - gec}$.

Where the numerator conſiſts of all the different products that can be made of three oppoſite coefficients taken from the orders in which $z$ is not found; and the denominator conſiſts of all the products that can be made of the three

oppoſite coefficients taken from the orders that involve the three unknown quantities. For, from the laſt it appears, that

$$y = \frac{an - afz - dm + dcz}{ae - db}, \text{ and that}$$

$$y = \frac{ap - akz - gm + gcz}{ab - gb}; \text{ therefore}$$

$$\frac{an - afz - dm + dcz}{ae - db} = \frac{ap - akz - gm + gcz}{ab - gb}, \text{ and}$$

$$\overline{an - afz - dm + dcz} \times ab - gb \times \overline{an - afz} + gbdm - gbdcz = \overline{ap - gm - akz + gcz} \times ae - db \times \overline{ap - akz} + gbdm - gbdcz.$$

Take $gbdm - gbdcz$ from both ſides, and divide by $a$, ſo ſhall

$$\overline{an - dm - afz + dcz} \times b - gbn + gbfz = \overline{ap - gm - akz + gcz} \times e - dbp + dbkz.$$

Tranſpoſe and divide, ſo ſhall you find

$$z = \frac{aep - abn + dbm - dbp + gen - gem}{aek - abf + dbc - dbk + gbf - gec}.$$

The values of $x$ and $y$ are found after the ſame manner, and have the ſame denominator. *Ex gr.*

$$y = \frac{afp - akn + dkm - dep + gen - gfm}{aek - abf + dbc - dbk + gbf - gec}.$$

If any term is wanting in any of the three given equations, the values of $z$ and $y$ will be found more ſimple. Suppoſe, for example, that $f$ and $k$ are equal to nothing, then the term $fz$ will vaniſh in the ſecond equation, and $kz$ in the third, and $z = \frac{aep - anb + dbm - dbp + gnb - gem}{dbc - gec}$;

$$y = \frac{gcn - dcp}{dbc - gec}.$$

If

ients taken from the orders that
ree unknown quantities. For,
appears, that
$\frac{-afz-dm+dkz}{ae-ab}$, and that
$\frac{-akz-gm+gez}{ab-gb}$; therefore
$\frac{kz}{-} = \frac{ap-akz-gm+gez}{ab-gb}$, and
$\overline{dcz} \times ab - gb \times \overline{an-afz} +$
$p - gm - akz + gez \times a -$
$bdm - gbdcz.$
$cz$ from both ſides, and di-

$\overline{dcz} \times b - gbn + gbfz =$
$\overline{gez} \times e - dbp + dbkz.$
e, ſo ſhall you find
$\frac{bp+gen-gem}{bk+gbf-gec}$. The va-
ind after the ſame manner,
nominator. *Ex gr.*
$\frac{p+gen-gfm}{k+gbf-gec}$.
ng in any of the three
alues of $z$ and $y$ will be
ppoſe, for example, that
hing, then the term $fz$
equation, and $kz$ in the
$\frac{+dhm-dbp+gnb-gem}{dbc-gec}$;

If



If four equations are given, involving four unknown quantities, their values may be found much after the ſame manner, by taking all the products that can be made of four oppoſite coefficients, and always prefixing contrary ſigns to thoſe that involve the products of two oppoſite coefficients.

## CHAP. XIII.

### Of Quadratic EQUATIONS.

§ 88. IN the ſolution of any queſtion where you have got an equation that involves one unknown quantity, but involves at the ſame time the ſquare of that quantity, and the product of it multiplied by ſome known quantity, then you have what is called a *Quadratic equation*; which may be reſolved by the following

#### RULE.

1. "*Tranſport all the terms that involve the unknown quantity to one ſide, and the known terms to the other ſide of the equation.*
2. *If the ſquare of the unknown quantity is multiplied by any coefficient, you are to divide all the terms by that coefficient, that the coefficient*

*of the ſquare of the unknown quantity may be unit.*

3. *Add to both ſides the ſquare of half the coefficient prefixed to the unknown quantity itſelf, and the ſide of the equation that involves the unknown quantity will then be a compleat ſquare.*

4. *Extract the ſquare root from both ſides of the equation; which you will find, on one ſide, always to be the unknown quantity with half the foreſaid coefficient ſubjoined to it; ſo that by tranſpoſing this half you may obtain the value of the unknown quantity expreſſed in known terms.*" Thus,

Suppoſe $y^2 + ay = b$,

Add the ſquare of $\frac{a}{2}$ to both ſides $\Big\}\ y^2 + ay + \frac{a^2}{4} = b + \frac{a^2}{4}$,

Extract the root, $y + \frac{a}{2} = \pm\sqrt{b + \frac{a^2}{4}}$,

Tranſpoſe $\frac{a}{2}$, $y = \pm\sqrt{b + \frac{a^2}{4}} - \frac{a}{2}$.

§ 89. The ſquare root of any quantity, as $+aa$, may be $+a$, or $-a$; and hence, "All quadratic equations admit of two ſolutions." In the laſt example, after finding that $y^2 + ay + \frac{a^2}{4} = b + \frac{a^2}{4}$, it may be inferred that $y + \frac{a}{2} = +\sqrt{b + \frac{a^2}{4}}$, or to $-\sqrt{b + \frac{a^2}{4}}$; ſince

of the unknown quantity may be

ſides the ſquare of half the coef-
to the unknown quantity itſelf,
of the equation that involves the
ntity will then be a compleat

uare root from both ſides of the
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unknown quantity with half
ficient ſubjoined to it; ſo that
his half you may obtain the va-
wn quantity expreſſed in known

poſe $y^2 + ay = b$,

$$\left.\begin{matrix} \frac{a}{} \\ \end{matrix}\right\} y^2 + ay + \frac{a^2}{4} = b + \frac{a^2}{4},$$

t, $y + \frac{a}{2} = \pm\sqrt{b + \frac{a^2}{4}}$,

$\frac{a}{}$, $y = \pm\sqrt{b + \frac{a^2}{4}} - \frac{a}{2}$.

root of any quantity, as
$-a$; and hence, "All
dmit of two ſolutions."
after finding that $y^2 +$
may be inferred that

to $-\sqrt{b+\frac{a^2}{4}}$; ſince



$-\sqrt{b+\frac{a^2}{4}} \times -\sqrt{b+\frac{a^2}{4}}$ gives $b+\frac{a^2}{4}$, as well as $+\sqrt{b+\frac{a^2}{4}} \times +\sqrt{b+\frac{a^2}{4}}$. There are therefore two values of $y$; the one gives $y = +\sqrt{b+\frac{a^2}{4}} - \frac{a}{2}$, the other $y = -\sqrt{b+\frac{a^2}{4}} - \frac{a}{2}$.

§ 90. Since the ſquares of all quantities are poſitive, it is plain that "The ſquare root of a negative quantity is imaginary, and cannot be aſſigned." Therefore there are ſome quadratic equations that cannot have any ſolution. For example,

Suppoſe $y^2 - ay + 3a^2 = 0$,
then $y^2 - ay = -3a^2$;
add $\frac{a^2}{4}$ to both, $y^2 - ay + \frac{a^2}{4} = -3a^2 + \frac{a^2}{4} = -\frac{11a^2}{4}$,
extract the root, $y - \frac{a}{2} = \pm\sqrt{-\frac{11a^2}{4}}$,
and $y = \frac{a}{2} \pm \sqrt{-\frac{11a^2}{4}}$:

whence the two values of $y$ muſt be imaginary or impoſſible, becauſe the root of $-\frac{11a^2}{4}$ cannot poſſibly be aſſigned.

But of this we ſhall treat more fully in the Second Part.

t the quadratic equation propoſed
is $y^2 - ay = b$;

$y^2 - ay + \frac{a^2}{4} = b + \frac{a^2}{4}$,

$y - \frac{a}{2} = \pm\sqrt{b + \frac{a^2}{4}}$,

$y = \frac{a}{2} \pm \sqrt{b + \frac{a^2}{4}}$.

ıt of $b + \frac{a^2}{4}$ cannot be extracted
ıft, in order to determine the
approximate to the value of

e Rules in *Chap.* 8. The fol-
will illuſtrate the Rule for
ıs.

MPLE I.

*ıber, which if you multiply by*
*be equal to the ſquare of the*
*12 added to it.*

*y*; then
$-12 = 8y$,
$\cdot\ 8y = -12$,
$8y + 16 = -12 + 16 = 4$,
$4 = \pm 2$,
$4 \pm 2 = 6$, or 2.

EXAMPLE



## EXAMPLE II.

*To find a number ſuch that if you ſubtract it from* 10, *and multiply the remainder by the number itſelf, the product ſhall give* 21.

Call it $y$; then

$10 - y \times y = 21$.

that is, $10y - yy = 21$;

tranſp. $y^2 - 10y = -21$,

add the ſq. of $5$, $y^2 - 10y + 25 = -21 + 25 = 4$

extr. the ſq. root $y - 5 = \pm\sqrt{4} = \pm 2$,

and $y = 5 \pm 2 = 7$, or 3.

## EXAMPLE III.

*The ſum of two quantities is* $a$, *their product* $b$. Qu. *What are the quantities?*

Suppoſe $\begin{cases} x + y = a \ldots \text{then } x = a - y, \\ xy = b \ldots\ldots \text{then } x = \frac{b}{y}, \end{cases}$

therefore $a - y = \frac{b}{y}$,

and $ay - y^2 = b$;

tranſp. $y^2 - ay = -b$,

add $\frac{a^2}{4} \ldots y^2 - ay + \frac{a^2}{4} = -b + \frac{a^2}{4}$,

extract $\surd$, $y - \frac{a}{2} = \pm\sqrt{-b + \frac{a^2}{4}}$,

and $y = \frac{a}{2} \pm \sqrt{-b + \frac{a^2}{4}}$,

$x\,(= a - y) = \frac{a}{2} \mp \sqrt{-b + \frac{a^2}{4}}$.

## EXAMPLE IV.

*The ſum of two quantities is a, and the ſum of their ſquares b.* Qu. *the quantities?*

Suppoſe $\begin{cases} x+y=a \ldots \text{then } x=a-y, \\ x^2+y^2=b \ldots\ldots x^2=b-y^2, \end{cases}$

involv. $x^2=a^2-2ay+y^2$,

whence $a^2-2ay+y^2=b-y^2$;

tranſp. and divide $\begin{cases} 2y^2-2ay=b-a^2, \\ y^2-ay=\frac{b-a^2}{2}, \end{cases}$

add $\frac{a^2}{4}$, $y^2-ay+\frac{a^2}{4}=\frac{b-a^2}{2}+\frac{a^2}{4}=\frac{2b-a^2}{4}$,

extr. $\surd$, $y-\frac{a}{2}=\pm\sqrt{\frac{2b-a^2}{4}}$; and $y=\frac{a}{2}\pm\sqrt{\frac{2b-a^2}{4}}$; $x\,(=a-y)=\frac{a}{2}\mp\sqrt{\frac{2b-a^2}{4}}$.

Or thus, $y=\frac{a\pm\sqrt{2b-a^2}}{2}$, and $x=\frac{a\pm\sqrt{2b-a^2}}{2}$.

## EXAMPLE V.

*A company dining together in an inn, find their bill amounts to* 175 *ſhillings; two of them were not allowed to pay, and the reſt found that their ſhares amounted to* 10 s. *a man more than if all had paid.* Qu. *How many were in company?*

Suppoſe their number $x$; then if all had paid each man's ſhare would have been $\frac{175}{x}$, ſeeing $x-2$ is the number of thoſe that pay. It is therefore, by the queſtion,

175

XAMPLE IV.

*two quantities is a, and the sm*
*b.* Qu. *the quantities?*

$y = a$ . . . then $x = a - y$,
$x^2 = b$ . . . . . $x^2 = b - y^2$,
$a^2 - 2ay + y^2$,
$ay + y^2 = b - y^2$;
$2y = b - a^2$,
$y = \frac{b-a^2}{2}$,

$+ \frac{a^2}{4} = \frac{b-a^2}{2} + \frac{a^2}{4} = \frac{2b-a^2}{4}$,

$= \pm \sqrt{\frac{2b-a^2}{4}}$; and $y = \frac{b}{2}$

$= a - y) = \frac{a}{2} \mp \sqrt{\frac{2b-a^2}{4}}$,

$\frac{-a^2}{}$, and $x = \frac{a \pm \sqrt{2b-a^2}}{2}$,

MPLE V.

*gether in an inn, find their*
*hillings; two of them wer*
*d the reſt found that their*
*s. a man more than if all*
*any were in company?*

er $x$; then if all had paid
I have been $\frac{175}{x}$, ſeeing
thoſe that pay. It is
on,

175



$$\frac{175}{x-2} - \frac{175}{x} = 10,$$

and $175x - 175x + 350 = 10x^2 - 20x$;
that is, $10x^2 - 20x = 350$,
and $x^2 - 2x = 35$;
add 1 . . $x^2 - 2x + 1 = 35 + 1 = 36$,
extr. $\sqrt{}$ . . $x - 1 = \pm 6$,
$x = 1 \pm 6 = 7$, or $-5$.

It is obvious that the poſitive value 7 gives the ſolution of the queſtion; the negative value $-5$ being, in the preſent caſe, uſeleſs.

## EXAMPLE VI.

*There are three numbers in continual geometrical proportion; the ſum of the firſt and ſecond is* 10, *and the difference of the ſecond and 3d is* 24. Qu. *the numbers?*

Let the firſt be $x$, and the ſecond will be $10 - x$, and the third, $34 - x$; therefore,

$x : 10 - x :: 10 - x : 34 - x$,
and $34x - x^2 = 100 - 20x + x^2$;
tranſp. $54x = 100 + 2x^2$,
and divid. $x^2 - 27x = -50$,
add $\frac{27}{2} \times \frac{27}{2}$ . . . $x^2 - 27x + \frac{729}{4} = \frac{729}{4} - 50 = \frac{529}{4}$,
extract $\sqrt{}$ . . . $x - \frac{27}{2} = \pm\sqrt{\frac{529}{4}} = \mp\frac{23}{2}$,
and $x = \frac{27+23}{2}$, or $= \frac{27-23}{2} = 25$, or 2.

So

So the three continued proportionals are

$2 : 8 : 32$, or

$25 : -15 : 9$.

§ 91. Any equation of this form $y^{2m}+ay^m=b$, where the greateſt index of the unknown quantity $y$ is double to the index of $y$ in the other term, may be reduced to a quadratic $z^2+az=b$, by putting $y^m=z$, and conſequently $y^{2m}=z^2$. And this quadratic reſolved as above, gives $z=-\frac{a}{2}\pm\sqrt{b+\frac{a^2}{4}}$.

And ſeeing $y^m=z=-\frac{a}{2}\pm\sqrt{b+\frac{a^2}{4}}$,

$y=\sqrt[m]{-\frac{a}{2}\pm\sqrt{b+\frac{a^2}{4}}}$.

## EXAMPLE I.

*The product of two quantities is a, and the ſum of their ſquares b.* Qu. *the quantities?*

Supp. $\begin{cases} xy=a \ldots \text{or, } x=\frac{a}{y}, & x^2=\frac{a^2}{y^2}, \\ x^2+y^2=b \ldots & x^2=b-y^2, \end{cases}$

whence $b-y^2=\frac{a^2}{y^2}$;

mult. by $y^2$ .. $by^2-y^4=a^2$,

tranſp. $y^4-by^2=-a^2$.

Put now $y^2=z$ ... and conſequently $y^4=z^2$, and it is

$z^2-$

ee continued proportionals are
2 : 8 : 32, or
25 : — 15 : 9.

quation of this form $y^{2m}+qy^{m}=$
ateſt index of the unknown quan
ble to the index of $y$ in the othe
educed to a quadratic $z^2+az=$
$= z$, and conſequently $y^m=z$
ratic reſolved as above, gives

$+\frac{a^2}{4}$.

$\cdot = z = -\frac{a}{2} \pm \sqrt{b+\frac{a^2}{4}}$,

$\sqrt{b+\frac{a^2}{4}}$.

AMPLE I.

*vo quantities is a, and the ſum*
Qu. *the quantities?*

$\ldots$ or, $x=\frac{a}{y}$, $x^2=\frac{a^2}{y^2}$,

$=b \ldots x^2=b-y^2$,

$=\frac{a^2}{y^2}$;

$=a^2$,

$=-a^2$.

and conſequently $y^4=z^2$,

$z^2-$



$z^2-bz=-a^2$;

add $\frac{b^2}{4}$, $z^2-bz+\frac{b^2}{4}=\frac{b^2}{4}-a^2$,

ext. $\sqrt{\ }$, $z-\frac{b}{2}=\pm\sqrt{\frac{b^2}{4}-a^2}$,

and $z=\frac{b}{2}\pm\sqrt{\frac{b^2}{4}-a^2}$; and, ſeeing $y=\sqrt{z}$,

$$y=\pm\sqrt{\frac{b}{2}\pm\sqrt{\frac{b^2}{4}-a^2}}.$$

## EXAMPLE II.

*To find a number from the cube of which if you ſubtract* 19, *and multiply the remainder by that cube, the product ſhall be* 216.

Call the number required $x$; and then, by the queſtion,

$x^3-19\times x^3=216$,

$x^6-19x^3=216$.

Put $x^3=z \ldots\ldots x^6=z^2$, and it will be

$z^2-19z+\frac{361}{4}=216+\frac{361}{4}=\frac{1225}{4}$,

and $\sqrt{\ }\ldots z-\frac{19}{2}=\pm\frac{35}{2}$;

whence $z=\frac{19\pm35}{2}=27$, or $=-8$.

But $x=\sqrt[3]{z}$; wherefore $x=+3$, or $-2$.

$\frac{19}{2}$ $\frac{19}{361}$ EX-

EXAMPLE III.

*To find the value of x, ſuppoſing that* $x^{\frac{2}{3}} - 7x^{\frac{1}{3}} = 8$.

Put $x^{\frac{1}{3}} = z$, and $x^{\frac{2}{3}} = z^2$;

then $z^2 - 7z = 8$,

$$z^2 - 7z + \frac{49}{4} = \frac{81}{4},$$

$$z - \frac{7}{2} = \pm\frac{9}{2},$$

$$z = 8.$$

But $x^{\frac{2}{3}} = z^2$, and $x = \sqrt[3]{z^2} = \sqrt[3]{64} = 4$.

## CHAP. XIV.

### Of SURDS.

§ 92. IF a leſſer quantity meaſures a greater ſo as to leave no remainder, as $2a$ meaſures $10a$, being found in it five times, it is ſaid to be an *aliquot* part of it, and the greater is ſaid to be a *multiple* of the leſſer. The leſſer quantity in this caſe is the *greateſt common meaſure* of the two quantities; for as it meaſures the greater, ſo it alſo meaſures itſelf, and no quantity can meaſure it that is greater than itſelf.

When a third quantity meaſures any two propoſed quantities, as $2a$ meaſures $6a$ and $10a$, it is

XAMPLE III.

value of $x$, ſuppoſing that $x^{\frac{2}{3}}+7x=8$.

it $x^{\frac{2}{3}}=z$, and $x^{\frac{4}{3}}=z^2$;
n $z^2-7z=8$,

$$z^2-7z+\frac{49}{4}=\frac{81}{4},$$

$$z-\frac{7}{2}=\pm\frac{9}{2},$$

$$z=8.$$

, and $x=\sqrt[3]{z^2}=\sqrt[3]{64}=4$.

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AP. XIV.

SURDS.

r quantity meaſures a greater leave no remainder, as 12 g found in it five times, it is part of it, and the greater ple of the leſſer. The leſſer e is the *greateſt common meaſure* tities; for as it meaſures the eaſures itſelf, and no quan- hat is greater than itſelf.

ntity meaſures any two pro- $2a$ meaſures $6a$ and $10a$, it is



is ſaid to be a *common meaſure* of theſe quantities; and if no greater quantity meaſure them both, is is called their *greateſt common* meaſure.

Thoſe quantities are ſaid to be *commenſurable* which have any common meaſure; but if there can be no quantity found that meaſures them both, they are ſaid to be *incommenſurable*; and if any one quantity be called *rational*, all others that have any common meaſure with it, are alſo called rational: But thoſe that have no common meaſure with it, are called *irrational* quantities.

§ 93. If any two quantities $a$ and $b$ have any common meaſure $x$, this quantity $x$ ſhall alſo meaſure their ſum or difference $a \mp b$. Let $x$ be found in $a$ as many times as unit is found in $m$, ſo that $a=mx$; and in $b$, as many times as unit is found in $n$, ſo that $b=nx$; then ſhall $a \mp b = mx \mp nx = \overline{m \mp n} \times x$; ſo that $x$ ſhall be found in $a \mp b$, as often as unit is found in $m \mp n$: Now ſince $m$ and $n$ are integer numbers, $m \mp n$ muſt be an integer number or unit, and therefore $x$ muſt meaſure $a \mp b$.

§ 94. It is alſo evident, that if $x$ meaſure any number as $a$, it muſt meaſure any multiple of that number. If it be found in $a$ as many times as unit is found in $m$, ſo that $a=mx$, then it will be found in any multiple of $a$, as $na$, as many times as unit is found in $mn$; for $na=mnx$.

§ 95.

§ 95. If two quantities $a$ and $b$ are propoſed, and $b$ meaſure $a$ by the units that are in $m$ (that is, be found in $a$ as many times as unit it found in $m$) and there be a remainder $c$; and if $x$ be ſuppoſed to be a common meaſure of $a$ and $b$, it ſhall be alſo a meaſure of $c$. For by the ſuppoſition $a = mb + c$, ſince it contains $b$ as many times as there are units in $m$, and there is $c$ beſides of remainder; therefore $a - mb = c$. Now $x$ is ſuppoſed to meaſure $a$ and $b$, and therefore it meaſures $mb$ (*Art.* 94.) and conſequently $a - mb$ (*Art.* 93.) which is equal to $c$.

If $c$ meaſures $b$ by the units in $n$, and there be a remainder $d$, ſo that $b = nc + d$, and $b - nc = d$, then ſhall $x$ alſo meaſure $d$; becauſe it is ſuppoſed to meaſure $b$, and it has been proved that it meaſures $c$, and conſequently $nc$, and $b - nc$ (by *Art.* 94.) which is equal to $d$. Whence, as after ſubtracting $b$ as often as poſſible from $a$, the remainder $c$ is meaſured by $x$; and after ſubtracting $c$ as often as poſſible from $b$, the remainder $d$ is alſo meaſured by $x$; ſo, for the ſame reaſon, if you ſubtract $d$ as often as poſſible from $c$, the remainder (if there be any) muſt ſtill be meaſured by $x$: and if you proceed, ſtill ſubtracting every remainder from the preceding remainder, till you find ſome remainder which ſubtracted from the preceding leaves no further remainder, but exactly meaſures it, this laſt

'o quantities *a* and *b* are propoſed,
: *a* by the units that are in *m* (the
n *a* as many times as unit it found
re be a remainder *c*; and if *x* be
oe a common meaſure of *a* and
lſo a meaſure of *c*. For by the
= *mb* + *c*, ſince it contains *b* a
there are units in *m*, and there
remainder; therefore *a* − *mb*
s ſuppoſed to meaſure *a* and *b*,
t meaſures *mb* (*Art.* 94.) and
— *mb* (*Art.* 93.) which is equal

by the units in *n*, and there be
hat *b* = *nc* + *d*, and *b* − *nc* = *d*
meaſure *d*; becauſe it is ſup-
*b*, and it has been proved that
conſequently *nc*, and *b* − *nc*
:h is equal to *d*. Whence, as
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eaſured by *x*; ſo, for the ſame
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laſt remainder will ſtill be meaſured by *x*, any common meaſure of *a* and *b*.

§ 96. The laſt of theſe remainders, *viz* that which exactly meaſures the preceding remainder, muſt be a common meaſure of *a* and *b*: ſuppoſe that *d* was this laſt remainder, and that it meaſured *c* by the units in *r*, then ſhall $c = rd$, and we ſhall have theſe equations.

$$a = mb + c,$$
$$b = nc + d,$$
$$c = rd.$$

Now it is plain that ſince *d* meaſures *c*, it muſt alſo meaſure *nc*, and therefore muſt meaſure $nc + d$, or *b*. And ſince it meaſures *b* and *c*, it muſt meaſure $mb + c$, or *a*; ſo that it muſt be a common meaſure of *a* and *b*. But further, it muſt be their *greateſt* common meaſure; for every common meaſure of *a* and *b* muſt meaſure *d*, by the laſt article; and the greateſt number that meaſures *d*, is itſelf, which therefore is the greateſt common meaſure of *a* and *b*.

§ 97. But if, by continually ſubtracting every remainder from the preceding remainder, you can never find one that meaſures that which precedes it, exactly, no quantity can be found that will meaſure both *a* and *b*; and therefore they will be *incommenſurable* to each other.

For if there was any common meaſure of theſe quantities, as *x*, it would neceſſarily meaſure all

all the remainders $c$, $d$, &c. For it would measure $a-mb$, or $c$, and consequently $b-nc$, or $d$; and so on. Now these remainders decrease in such a manner, that they will necessarily become at length less than $x$, or any assignable quantity: for $c$ must be less than $\frac{1}{2}a$; because $c$ is less than $b$, and therefore less than $mb$, and consequently less than $\frac{1}{2}c+\frac{1}{2}mb$, or $\frac{1}{2}a$. In like manner $d$ must be less than $\frac{1}{2}b$; for $d$ is less than $c$, and consequently less than $\frac{1}{2}d+\frac{1}{2}nc$, or $\frac{1}{2}b$. The third remainder, in the same manner, must be less than $\frac{1}{2}c$, which is itself less than $\frac{1}{4}a$; thus these remainders decrease so, that every one is less than the half of that which preceded it next but one. Now if from any quantity you take away more than its half, and from the remainder more than its half, and proceed in this manner, you will come at a remainder less than any assignable quantity. It appears therefore that if the remainders $c$, $d$, &c. never end, they will become less than any assignable quantity, as $x$, which therefore cannot possibly measure them, and therefore cannot be a common measure of $a$ and $b$.

§ 98. In the same way, the greatest common measure of two numbers is discovered. Unit is a common measure of all integer numbers, and two numbers are said to be *prime* to each other, when they have no greater common measure than unit; such as 9 and 25. Such always

nders $c$, $d$, &c. For it would
, or $c$, and consequently $b-x$,
on. Now these remainders do
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length less than $x$, or any assign-
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an $b$, and therefore less than $mb$,
y less than $\frac{1}{a}c+\frac{1}{a}mb$, or $\frac{1}{a}a$. In
ust be less than $\frac{1}{a}b$; for $d$ is less
equently less than $\frac{1}{a}d+\frac{1}{a}n$, or
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said to be *prime* to each
no greater common mea-
9 and 25. Such always
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are the least numbers that can be assumed in any given proportion; for if these had any common measure, then the quotients that would arise by dividing them by that common measure would be in the same proportion, and being less then the numbers themselves, these numbers would not be the least in the same proportion; against the supposition.

§ 99. The least numbers in any proportion always measure any other numbers that are in the same proportion. Suppose $a$ and $b$ to be the least of all integer numbers in the same proportion, and that $c$ and $d$ are other numbers in that proportion, then will $a$ measure $c$, and $b$ measure $d$.

For if $a$ and $b$ are not aliquot parts of $c$ and $d$, then they must contain the same number of the same kind of parts of $c$ and $d$, and therefore dividing $a$ into parts of $c$, and $b$ into an equal number of like parts of $d$, and calling one of the first $m$, and one of the latter $n$; then as $m$ is to $n$, so will the sum of all the $m$'s be to the sum of all the $n$'s; that is, $m : n :: a : b$; therefore $a$ and $b$ will not be the least in the same proportion; against the supposition. Therefore $a$ and $b$ must be aliquot parts of $c$ and $d$. Hence we see that numbers which are prime to each other are the least in the same proportion; for if there were others in the same proportion less than them, these would measure them by the same

ſame number, which therefore would be their common meaſure againſt the ſuppoſition, for we ſuppoſed them to be prime to each other.

§ 100. If two numbers $a$ and $b$ are prime to one another, and a third number $c$ meaſures one of them $a$, it will be prime to the other $b$. For if $c$ and $b$ were not prime to each other, they would have a common meaſure, which becauſe it would meaſure $c$, would alſo meaſure $a$, which is meaſured by $c$, therefore $a$ and $b$ would have a common meaſure, againſt the ſuppoſition.

§ 101. If two numbers $a$ and $b$ are prime to $c$, then ſhall their product $ab$ be alſo prime to $c$: For if you ſuppoſe them to have any common meaſure as $d$, and ſuppoſe that $d$ meaſures $ab$ by the units in $e$, ſo that $de = ab$, then ſhall $d : a :: b : e$. But ſince $d$ meaſures $c$, and $c$ is ſuppoſed to be prime to $a$, it follows (by *Art.* 100.) that $d$ and $a$ are prime to each other; and therefore (by *Art.* 99.) $d$ muſt meaſure $b$; and yet ſince $d$ is ſuppoſed to meaſure $c$, which is prime to $b$, it follows that $d$ is alſo prime to $b$: that is, $d$ is prime to a number which it meaſures, which is abſurd.

§ 102. It follows from the laſt article, that if $a$ and $c$ are prime to each other, then $a^2$ will be prime to $c$: For by ſuppoſing that $a$ is equal to $b$, then $ab$ will be equal to $a^2$; and conſequently $a^2$ will be prime to $c$. In the ſame manner $c^2$ will be prime to $a$.

§ 103.

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*c*, therefore *a* and *b* would have
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ll be equal to $a^2$; and conſe-
be prime to *c*. In the ſame
prime to *a*.

§ 103.



§ 103. If two numbers *a* and *b*, are both prime to other two *c*, *d*, then ſhall the product *ab* be prime to the product *cd*; for (by *Art.* 101.) *ab* will be prime to *c* and alſo to *d*, and therefore, by the ſame article, *cd* will be prime to *ab*.

§ 104. From this it follows, that if *a* and *c* are prime to each other, then ſhall $a^2$ be prime to $c^2$, by ſuppoſing, in the laſt, that $a = b$, and $c = d$. It is alſo evident that $a^3$ will be prime to $c^3$, and in general any power of *a* to any power of *c* whatſoever.

§ 105. Any two numbers, *a* and *b*, being given, to find the leaſt numbers that are in the ſame proportion with them, *divide them by their greateſt common meaſure x*, and *the quotients c and d ſhall be the leaſt numbers in the ſame proportion with a and b.*

For if there could be any other numbers in that proportion leſs than *c* and *d*, ſuppoſe them to be *e* and *f*, and theſe being in the ſame proportion as *a* and *b* would meaſure them: And the number by which they would meaſure them, would be greater than *x*, becauſe *e* and *f* are ſuppoſed leſs than *c* and *d*, ſo that *x* would not be the greateſt common meaſure of *a* and *b*; againſt the ſuppoſition.

§ 106. Let it be required to find the leaſt number that any two given numbers as *a* and *b* can meaſure. Firſt, *if they are prime to each*

*other, then their product ab is the leaſt number which they can both meaſure.*

For if they could meaſure a leſs number than *ab* as *c*, ſuppoſe that *c* is equal to *ma*, and to *nb*; and ſince *c* is leſs than *ab*, therefore *ma* will be leſs than *ab*, and *m* leſs than *b*; and *n* being leſs than *ab*, it follows that *n* muſt be leſs than *a*; but ſince $ma=nb$, and conſequently $a:b::n:m$, and *a* and *b* are prime to each other, it would follow that *a* would meaſure *n*, and *b* meaſure *m*; that is, a greater number would meaſure a leſs, which is abſurd.

But if the numbers *a* and *b* are not prime to each other, and their greateſt common meaſure is *x*, which meaſures *a* by the units in *m*, and meaſures *b* by the units in *n*, ſo that $a=mx$, and $b=nx$; then ſhall *an* (which is equal to *bm*, becauſe $a:b::mx:nx::m:n$, and therefore $an=bm$) be the leaſt number that *a* and *b* can both meaſure. For if they could meaſure any number *c* leſs than *na*, ſo that $c=la=kb$, then $a:b::m:n::k:l$; and becauſe *x* is ſuppoſed to be the greateſt common meaſure of *a* and *b*, it follows that *m* and *n* are the leaſt of all numbers in the ſame proportion, and therefore *m* meaſures *k*, and *n* meaſures *l*. But as *c* is ſuppoſed to be leſs than *na*, that is, *la* leſs than *na*, therefore *l* is leſs than *n*, ſo that a greater would meaſure a leſſer, which is abſurd. Therefore *a* and *b* cannot meaſure any number leſs than

*na*;

*eir product ab is the leaſt numbe*
*both meaſure.*

could meaſure a leſs number than
that *c* is equal to *ma*, and to *n*
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number that *a* and *b* can
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*na*, ſo that *c* = *la* = *kb*, then
and becauſe *x* is ſuppoſed
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es *l*. But as *c* is ſuppoſed
that is, *la* leſs than *na*,
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e any number leſs than
*na*;



*na*; which they both meaſure, becauſe *na* = *mb*.

It follows from this reaſoning, that if *a* and *b* meaſure any quantity *c*, the leaſt quantity *na*, which is meaſured by *a* and *b*, will alſo meaſure *c*. For if you ſuppoſe as before that *c* = *la*, you will find that *n* muſt meaſure *l*, and *na* muſt meaſure *la* or *c*.

§ 107. Let *a* expreſs any integer number, and $\frac{m}{n}$ any fraction reduced to its loweſt terms, ſo that *m* and *n* may be prime to each other, and conſequently *an* + *m* alſo prime to *n*, it will follow that $\overline{an+m}^{2}$ will be prime to $n^2$, and conſequently $\frac{\overline{an+m}^{2}}{n^2}$ will be a fraction in its leaſt terms, and can never be equal to an integer number. Therefore the ſquare of the mixt number $a + \frac{m}{n}$ is ſtill a mixt number, and never an integer. In the ſame manner the cube, biquadrate, or any power of a mixt number, is ſtill a mixt number, and never an integer. It follows from this, that *the ſquare root of an integer muſt be an integer or an incommenſurable.* Suppoſe that the integer propoſed is B, and that the ſquare root of it is leſs than $a+1$, but greater than *a*, than it muſt be an incommenſurable; for if it is a commenſurable, let it be $a + \frac{m}{n}$ where $\frac{m}{n}$ repreſents any fraction reduced

to its leaſt terms; it would follow that $a + \frac{m}{n}$ ſquared would give an integer number B, the contrary of which we have demonſtrated.

§ 108. It follows from the laſt article, that *the ſquare roots of all numbers but of* 1, 4, 9, 16, 25, 36, 49, 64, 81, 100, 121, 144, &c. (which are the ſquares of the integer numbers 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, *&c.*) *are incommenſurables*; after the ſame manner, *the cube roots of all numbers but of the cubes of* 1, 2, 3, 4, 5, 6, 7, 8, 9, *&c.* are *incommenſurables*: and quantities that are to one another in the proportion of ſuch numbers muſt alſo have their ſquare roots or cube roots incommenſurable.

§ 109. The roots of ſuch numbers being incommenſurable are expreſſed therefore by placing the proper radical ſign over them; thus, $\sqrt{2}, \sqrt{3}, \sqrt{5}, \sqrt{6}, \sqrt{7}, \sqrt{8}, \sqrt{10}$, *&c.* expreſs numbers incommenſurable with unit. Theſe numbers, though they are incommenſurable themſelves with unit, are *commenſurable in power* with it, becauſe their powers are integers, that is, multiples of unit. They may alſo be commenſurable ſometimes with one another, as the $\sqrt{8}$, and the $\sqrt{2}$, becauſe they are to one another as 2 to 1: And when they have a com-

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d give an integer number B, the
hich we have demonſtrated.
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49, 64, 81, 100, 121, 144, &c.
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6, 7, 8, 9, 10, 11, 12, &c.) are
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6, $\sqrt{7}$, $\sqrt{8}$, $\sqrt{10}$, &c. expreſs
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$\sqrt{2}$ is the common meaſure
of



of both, then their ratio is reduced to an expreſſion in the leaſt terms, as that of commenſurable quantities, by dividing them by their greateſt common meaſure. This common meaſure is found as in commenſurable quantities, only the root of the common meaſure is to be made their common diviſor. Thus $\frac{\sqrt{12}}{\sqrt{3}} = \sqrt{4} = 2$, and $\frac{\sqrt{18a}}{\sqrt{2}} = 3\sqrt{a}$.

§ 110. A rational quantity may be reduced to the form of any given ſurd, by raiſing the quantity to the power that is denominated by the name of the ſurd, and then ſetting the radical ſign over it thus, $a = \sqrt[2]{a^2} = \sqrt[3]{a^3} = \sqrt[4]{a^4} = \sqrt[5]{a^5} = \sqrt[n]{a^n}$, and $4 = \sqrt{16} = \sqrt[3]{64} = \sqrt[4]{256} = \sqrt[5]{1024} = \sqrt[n]{4^n}$.

§ 111. As ſurds may be conſidered as powers with fractional exponents, *they are reduced to others of the ſame value that ſhall have the ſame radical ſign, by reducing theſe fractional exponents to fractions having the ſame value and a common denominator.* Thus $\sqrt[n]{a} = a^{\frac{1}{n}}$, and $\sqrt[m]{a} = a^{\frac{1}{m}}$, and $\frac{1}{n} = \frac{m}{nm}$, $\frac{1}{m} = \frac{n}{nm}$, and therefore $\sqrt[n]{a}$ and $\sqrt[m]{a}$, reduced to the ſame radical

ſign, become $\sqrt[mn]{a^m}$ and $\sqrt[mn]{a^n}$. If you are to reduce $\sqrt[x]{3}$ and $\sqrt[y]{2}$ to the ſame denominator, conſider $\sqrt[x]{3}$ as equal to $3^{\frac{1}{x}}$, the $\sqrt[y]{2}$ as equal to $2^{\frac{1}{y}}$, whoſe indices reduced to a common denominator, you have $3^{\frac{1}{x}} = 3^{\frac{1}{xy}}$ and $2^{\frac{1}{y}} = 2^{\frac{x}{xy}}$, and conſequently $\sqrt[x]{3} = \sqrt[xy]{3^y} = \sqrt[xy]{27}$, and $\sqrt[y]{2} = \sqrt[xy]{2^x} = \sqrt[xy]{4}$; ſo that the propoſed ſurds $\sqrt[x]{3}$ and $\sqrt[y]{2}$ are reduced to other equal ſurds $\sqrt[xy]{27}$ and $\sqrt[xy]{4}$, having a common radical ſign.

§ 112. *Surds of the ſame rational quantity are multiplied by adding their exponents, and divided by ſubtracting them.*

Thus $\sqrt[x]{a} \times \sqrt[y]{a} = a^{\frac{1}{x}} \times a^{\frac{1}{y}} = a^{\frac{y+x}{xy}} = a^{\frac{1}{xy}} = \sqrt[xy]{a^y}$;

and $\frac{\sqrt[x]{a}}{\sqrt[y]{a}} = \frac{a^{\frac{1}{x}}}{a^{\frac{1}{y}}} = a^{\frac{1}{x}-\frac{1}{y}} = a^{\frac{y-x}{xy}} = a^{\frac{1}{xy}} = \sqrt[xy]{a^y}$;

$\sqrt[m]{a} \times \sqrt[n]{a} = a^{\frac{n+m}{mn}}$; $\frac{\sqrt[m]{a}}{\sqrt[n]{a}} = a^{\frac{n-m}{mn}}$; $\sqrt[2]{2} \times \sqrt[3]{2} =$

$\sqrt[6]{2^5} = \sqrt[6]{32}$; $\frac{\sqrt[2]{2}}{\sqrt[3]{2}} = \sqrt[6]{2}$.

§ 113. If the ſurds are of different rational quantities, as $\sqrt[n]{a^x}$ and $\sqrt[n]{b^y}$, and have the ſame ſign, *multiply theſe rational quantities into one another*

$\sqrt[mn]{a^m}$ and $\sqrt[mn]{a^n}$. If you are to re
$\sqrt[3]{2}$ to the ſame denominator, co
qual to $3^{\frac{1}{2}}$, the $\sqrt[3]{2}$ as equal to
ices reduced to a common deno
have $3^{\frac{1}{2}} = 3^{\frac{3}{6}}$ and $2^{\frac{1}{3}} = 2^{\frac{2}{6}}$, and
$\sqrt[6]{3} = \sqrt[6]{3^3} = \sqrt[6]{27}$, and $\sqrt[3]{2} = \sqrt[6]{2^2}$
the propoſed ſurds $\sqrt[2]{3}$ and $\sqrt[3]{2}$
other equal ſurds $\sqrt[6]{27}$ and $\sqrt[6]{4}$
on radical ſign.

*of the ſame rational quantity an*
*ing their exponents, and divided*
*n.*

$= a^{\frac{1}{2}} \times a^{\frac{1}{3}} = a^{\frac{3+2}{6}} = a^{\frac{5}{6}} = \sqrt[6]{a^5}$;

$a^{\frac{1}{3}} - \frac{1}{5} = a^{\frac{5-3}{15}} = a^{\frac{2}{15}} = \sqrt[15]{a^2}$;

; $\frac{\sqrt[m]{a}}{\sqrt[n]{a}} = a^{\frac{n-m}{mn}}$; $\sqrt[2]{2} \times \sqrt[3]{2} =$

$= \sqrt[6]{2}$.

*ds are of different rational*

d $\sqrt[n]{b^1}$, and have the ſame
*rational quantities into one*
*another*



*another, or divide them by one another, and ſet the common radical ſign over their product or quotient.* Thus $\sqrt[n]{a^1} \times \sqrt[n]{b^1} = \sqrt[n]{a^1 b^1}$;

$\sqrt[3]{2} \times \sqrt[3]{5} = \sqrt[3]{10}$; $\frac{\sqrt[m]{a^1}}{\sqrt[m]{b^1 a}} = \sqrt[m]{\frac{a^1}{b^1 a}} = \sqrt[m]{\frac{a^1}{b^1}}$;

$\frac{\sqrt[3]{9}}{\sqrt[3]{24}} = \sqrt[3]{\frac{9}{24}} = \sqrt[3]{\frac{3}{8}} = \frac{1}{2}\sqrt[3]{3}$.

If the ſurds have not the ſame radical ſign, *reduce them by the* 11*th* Art. *to ſuch as ſhall have the ſame radical ſign, and proceed as before.* Thus

$\sqrt[m]{a} \times \sqrt[n]{b} = \sqrt[mn]{a^n b^m}$; $\frac{\sqrt[m]{a}}{\sqrt[n]{x}} = \sqrt[mn]{\frac{a^n}{x^m}}$; $\sqrt[2]{2} \times \sqrt[3]{4} =$

$2^{\frac{1}{2}} \times 4^{\frac{1}{3}} = 2^{\frac{3}{6}} \times 4^{\frac{2}{6}} = \sqrt[6]{2^3 \times 4^2} = \sqrt[6]{8 \times 16}$

$= \sqrt[6]{128}$; $\frac{\sqrt[3]{4}}{\sqrt[2]{2}} = \frac{4^{\frac{1}{3}}}{2^{\frac{1}{2}}} = \frac{4^{\frac{2}{6}}}{2^{\frac{3}{6}}} = \sqrt[6]{\frac{4^2}{2^3}} = \sqrt[6]{\frac{16}{8}}$

$= \sqrt[6]{2}$. If the ſurds have any rational coefficients, their product or quotient muſt be prefixed. Thus $2\sqrt[2]{3} \times 5\sqrt[2]{6} = 10\sqrt[2]{18}$.

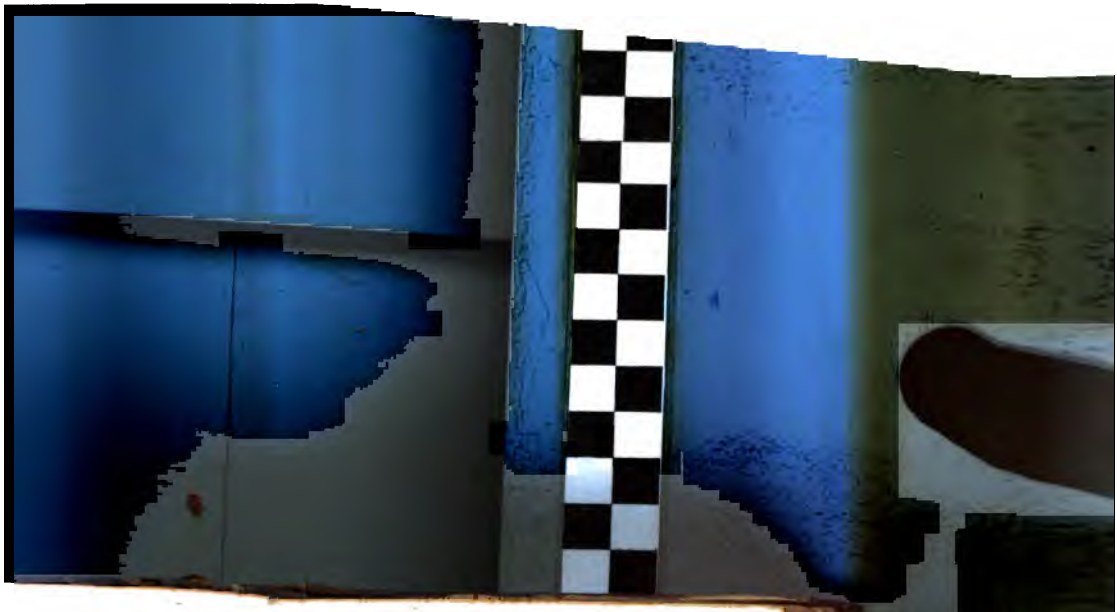
§ 114. The powers of ſurds are found as the powers of other quantities, *by multiplying their exponents by the index of the power required.* Thus the ſquare of $\sqrt[3]{2}$ is $2^{\frac{1}{3} \times 2} = 2^{\frac{2}{3}} = \sqrt[3]{4}$; the cube

cube of $\sqrt[3]{5} = 5^{\frac{1}{3}\times 3} = 5^{\frac{3}{3}} = \sqrt[3]{125}$. Or you need only, in involving ſurds, *raiſe the quantity under the radical ſign to the power required, continuing the ſame radical ſign; unleſs the index of that power is equal to the name of the ſurd, or a multiple of it, and in that caſe the power of the ſurd becomes rational.* Evolution is performed *by dividing the fraction which is the exponent of the ſurd by the name of the root required.*

Thus the ſquare root of $\sqrt[1]{a^2}$ is $\sqrt[2]{a^2}$, or $\sqrt[6]{a^3}$.

§ 115. The ſurd $\sqrt[m]{a^m x} = a\sqrt[m]{x}$; and in like manner, if a power of any quantity of the ſame name with the ſurd divides the quantity under the radical ſign without a remainder, as here $a^m$ divides $a^m x$, and 25 the ſquare of 5 divides 75, the quantity under the ſign in $\sqrt[2]{75}$, without a remainder, then place the root of that power rationally before the ſign, and the quotient under the ſign, and thus the ſurd will be reduced to a more ſimple expreſſion. Thus $\sqrt[2]{75} = 5\sqrt[2]{3}$; $\sqrt[2]{48} = \sqrt[2]{3\times 16} = 4\sqrt[2]{3}$; $\sqrt[3]{81} = \sqrt[3]{27\times 3} = 3\sqrt[3]{3}$.

§ 116. When ſurds by the laſt article are reduced to their leaſt expreſſions, if they have the ſame irrational part, they are added or ſub-





$= 5^{\frac{1}{2}\times 3} = 5^{\frac{3}{2}} = \sqrt[2]{125}$. Or you involving ſurds, *raiſe the quantity under the radical ſign to the power required, and retain the same radical ſign; unleſs the index of it is equal to the name of the ſurd, in which caſe it, and in that caſe the power of the quantity is rational.* Evolution is performed *by dividing the fraction which is the exponent of the ſurd by the name of the root required.*

The root of $\sqrt[3]{a^2}$ is $\sqrt[3]{a^1}$, or $\sqrt[3]{a}$.

The root $\sqrt[m]{a^m x} = a\sqrt[m]{x}$; and in like manner of any quantity of the ſame form. The root divides the quantity under the ſign without a remainder, as here the ſquare root of 25 the ſquare of 5 divides $\sqrt{75}$, under the ſign in $\sqrt[2]{75}$, without remainder; then place the root of that quantity before the ſign, and the quotient within the ſign, and thus the ſurd will be reduced to more ſimple expreſſion. Thus $\sqrt[2]{48} = \sqrt[2]{3\times 16} = 4\sqrt[2]{3}$; $\sqrt[3]{81} = 3\sqrt[3]{3}$.

Surds reduced by the laſt article are reduced to their leaſt expreſſions, if they have any, and if they are added or ſubtracted,



tracted, *by adding or ſubtracting their rational coefficients, and prefixing the ſum or difference to the common irrational part.*

Thus $\sqrt[3]{75} + \sqrt[3]{48} = 5\sqrt[3]{3} + 4\sqrt[3]{3} = 9\sqrt[3]{3}$; $\sqrt[3]{81} + \sqrt[3]{24} = 3\sqrt[3]{3} + 2\sqrt[3]{3} = 5\sqrt[3]{3}$; $\sqrt[3]{150} - \sqrt[3]{54} = 5\sqrt[3]{6} - 3\sqrt[3]{6} = 2\sqrt[3]{6}$; $\sqrt{a^2x} + \sqrt{b^2x} = a\sqrt{x} + b\sqrt{x} = \overline{a+b}\times\sqrt{x}$.

§ 117. *Compound ſurds* are ſuch as conſiſt of two or more joined together. The ſimple ſurds are commenſurable in power, and by being multiplied into themſelves give at length rational quantities; yet compound ſurds multiplied into themſelves commonly give ſtill irrational products. But when any compound ſurd is propoſed, *there is another compound ſurd which multiplied into it gives a rational product.* Thus $\sqrt{a} + \sqrt{b}$ multiplied by $\sqrt{a} - \sqrt{b}$ gives $a - b$, and *the inveſtigation of that ſurd which multiplied into the propoſed ſurd will give a rational product*, is made eaſy by the following Theorems.

## THEOREM I.

§ 118. Generally, if you multiply $a^n - b^n$ by $a^{n-m} + a^{n-2m}b^m + a^{n-3m}b^{2m} + a^{n-4m}b^{3m}$, &c. continued till the terms be in number equal to $\frac{n}{m}$, the product ſhall be $a^n - b^n$: for

$a^{n-m}$

$a^{n-m}+a^{n-2m}b^m+a^{n-3m}b^{2m}+a^{n-4m}b^{3m}$, &c. . . $b^{n-m}$

$\times\ a^m-b^m$

$a^n+a^{n-m}b^m+a^{n-2m}b^{2m}+a^{n-3m}b^{3m}$, &c.

$-a^{n-m}b^m-a^{n-2m}b^{2m}-a^{n-3m}b^{3m}$, &c. $-b^n$

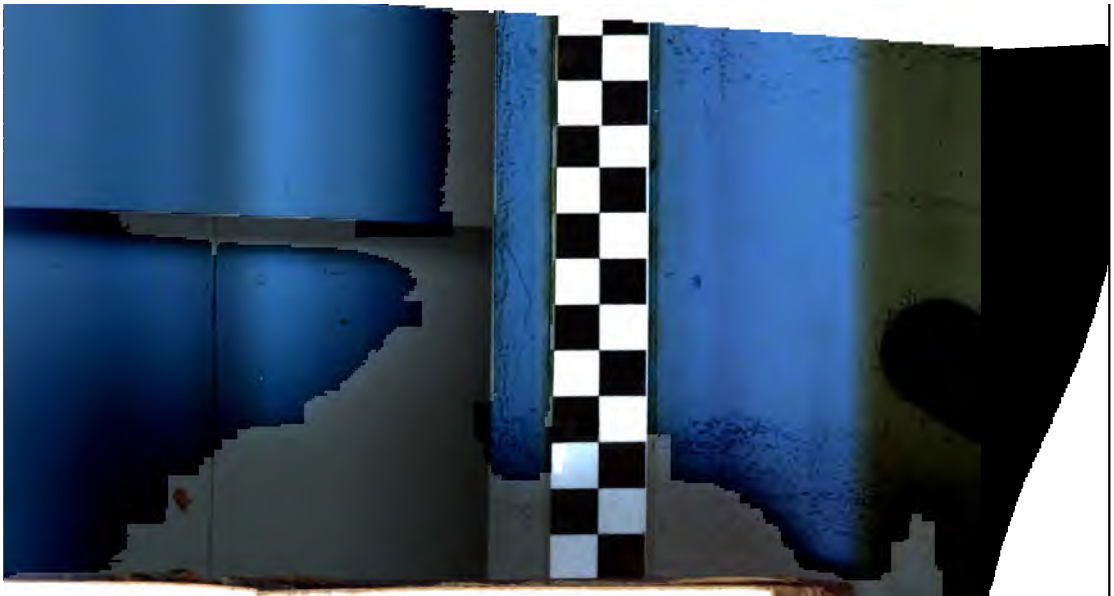
$a^n$ * * * $-b^n$

## THEOREM II.

$a^{n-m}-a^{n-2m}b^m+a^{n-3m}b^{2m}-a^{n-4m}b^{3m}$, &c. multiplied by $a^m+b^m$, gives $a^n\mp b^n$, which is demonſtrated as the other. Here the ſign of $b^n$ is poſitive, when $\frac{n}{m}$ is an odd number.

§ 119. When any binomial ſurd is propoſed, *ſuppoſe the index of each number equal to m, and let n be the leaſt integer number that is meaſured by m, then ſhall* $a^{n-m}\pm a^{n-2m}b^m+a^{n-3m}b^{2m}$, &c. *give a compound ſurd, which multiplied into the propoſed ſurd* $a^m\mp b^m$ *will give a rational product.* Thus to find the ſurd which multiplied by $\sqrt[3]{a}-\sqrt[3]{b}$, will give a rational quantity. Here $m=\frac{1}{3}$, and the leaſt number which is meaſured by $\frac{1}{3}$ is unit; let $n=1$, then ſhall $a^{n-m}+a^{n-2m}b^m+a^{n-3m}b^{2m}$, &c. $=a^{1-\frac{1}{3}}+a^{1-\frac{2}{3}}b^{\frac{1}{3}}+a^0b^{\frac{2}{3}}=a^{\frac{2}{3}}+a^{\frac{1}{3}}b^{\frac{1}{3}}+b^{\frac{2}{3}}=\sqrt[3]{a^2}+\sqrt[3]{ab}+\sqrt[3]{b^2}$, which multiplied by $\sqrt[3]{a}-\sqrt[3]{b}$, gives $a-b$.

To





$\ldots b^m + a^{n-3m}b^{2m} + a^{n-4m}b^{3m}$, &c. $\ldots b^{n-1}$

$a^{n-2m}b^{2m} + a^{n-3m}b^{3m}$, &c.
$a^{n-2m}b^{2m} - a^{n-3m}b^{3m}$, &c. $-b^n$

* * $-b^n$

## THEOREM II.

$\ldots b^m + a^{n-3m}b^{2m} - a^{n-4m}b^{3m}$, &c.
$a^m + b^m$, gives $a^n \mp b^n$, which
l as the other. Here the sign
when $\frac{n}{m}$ is an odd number.

any binomial ſurd is propoſed,
*if each number equal to m, and*
*integer number that is meaſurd*
$\ldots - m \pm a^{n-2m}b^m + a^{n-3m}b^{2m}$, &c.
*ſurd, which multiplied into the*
$\ldots b^m$ *will give a rational product.*
e ſurd which multiplied by
e a rational quantity. Here
eaſt number which is mea-
nit; let $n = 1$, then ſhall
$a^{n-3m}b^{2m}$, &c. $= a^{1-\frac{1}{3}} +$
$a^{\frac{2}{3}}b^{\frac{1}{3}} + a^{\frac{1}{3}}b^{\frac{2}{3}} + b^{\frac{3}{3}} = \sqrt[3]{a^2} +$
multiplied by $\sqrt[3]{a} - \sqrt[3]{b}$,

To



To find the ſurd which multiplied by $\sqrt[4]{a^3} + \sqrt[4]{b^3} = a^{\frac{3}{4}} + b^{\frac{3}{4}}$, gives a rational product. Here $m = 4$ and $n = 3$, and $a^{n-m} - a^{n-2m}b^m + a^{n-3m}b^{2m}$, &c. $= a^{3-\frac{4}{4}} - a^{3-\frac{8}{4}}b^{\frac{4}{4}} + a^{3-\frac{12}{4}}b^{\frac{8}{4}} - a^{3-3}b^{\frac{12}{4}} = a^{\frac{2}{4}} - a^{\frac{6}{4}}b^{\frac{4}{4}} + a^{\frac{3}{4}}b^{\frac{6}{4}} - b^{\frac{9}{4}} = \sqrt[4]{a^2} - \sqrt[4]{a^2b^1} + \sqrt[4]{a^1b^2} - \sqrt[4]{b^3}$.

## THEOREM III.

§ 120. Let $a^m \pm b^l$ be multiplied by $a^{n-m} \mp a^{n-2m}b^l + a^{n-3m}b^{2l} \mp a^{n-4m}b^{3l} + \mathcal{C}c.$ and the product ſhall give $a^n \pm b^{\frac{nl}{m}}$: *therefore n muſt be taken the leaſt integer that ſhall give* $\frac{nl}{m}$ *alſo an integer.*

Dem. $a^{n-m} \mp a^{n-2m}b^l + a^{n-3m}b^{2l} \mp a^{n-4m}b^{3l} \ldots$ ?

$\times \; a^m \pm b^l \qquad [\ldots$ &c. $a^0 b^{\frac{n}{m}l} - 1 \times l$

$a^n \mp a^{n-m}b^l + a^{n-2m}b^{2l}$, &c.

$\pm a^{n-m}b^l - a^{n-2m}b^{2l}$, &c. $\pm b^{\frac{n}{m}l}$

$a^n \quad * \quad * \quad * \quad \pm b^{\frac{n}{m}l}$.

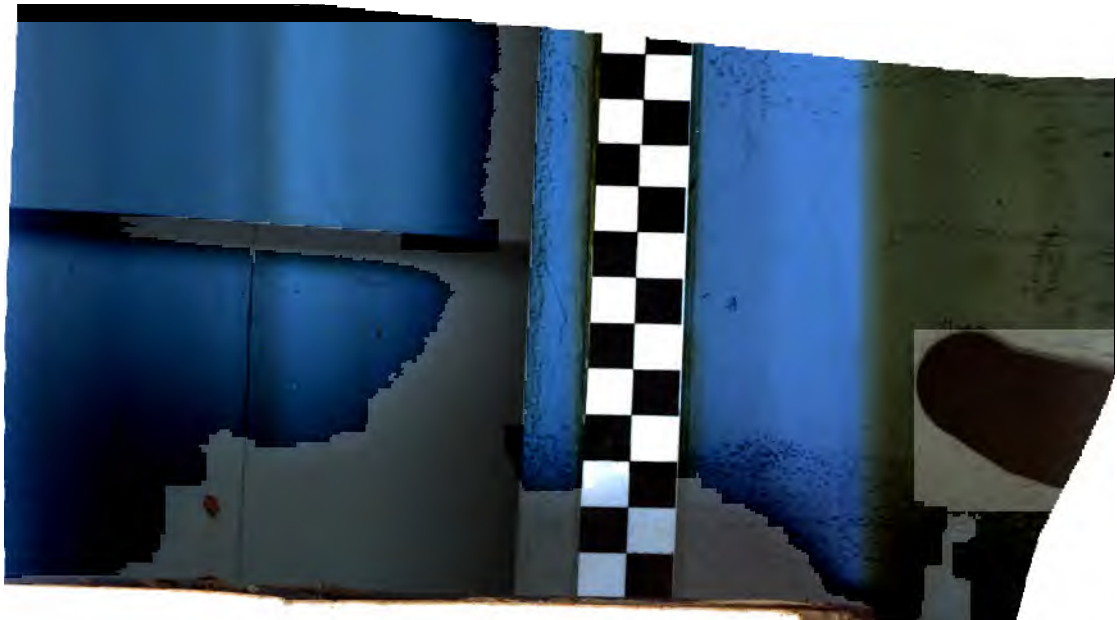
The ſign of $b^{\frac{nl}{m}}$ is poſitive only when $\frac{n}{m}$ is an odd number, and the binomial propoſed is $a^m + b^l$.

§ 121.

§ 121. If any binomial ſurd is propoſed whoſe two numbers have different indices, let theſe be $m$ and $l$, and take $n$ equal to the leaſt integer number that is meaſured by $m$ and by $\frac{m}{l}$; and $a^{n-m} \mp a^{n-2m}b^l + a^{n-3m}b^{2l} \mp a^{n-4m}b^{3l}$, &c. ſhall give a compound ſurd, which multiplied by the propoſed $a^m \pm b^l$ ſhall give a rational product. Thus $\sqrt[3]{a} - \sqrt[2]{b}$ being given, ſuppoſe $m = \frac{1}{3}$, $l = \frac{1}{2}$, and $\frac{m}{l} = \frac{2}{3}$, therefore you have $n=3$, and $a^{n-m} + a^{n-2m}b^l + a^{n-3m}b^{2l} + a^{n-4m}b^{3l}$ + &c. $= a^{3-\frac{1}{3}} + a^{3-\frac{2}{3}}b^{\frac{1}{2}} + a^{3-\frac{3}{3}}b^{\frac{2}{2}} + a^{3-\frac{4}{3}}b + a^{3-\frac{5}{3}}b^{\frac{5}{2}} + a^{3-\frac{6}{3}}b^{\frac{6}{2}} = a^{\frac{8}{3}} + a^{\frac{7}{3}}b^{\frac{1}{2}} + a^{\frac{6}{3}}b^{\frac{2}{2}} + ab + a^{\frac{4}{3}}b^{\frac{4}{2}} + b^{\frac{5}{2}} = \sqrt[3]{a^8} + a^2 \times \sqrt[3]{b} + \sqrt[3]{a^7} \times \sqrt[3]{b^2} + ab + \sqrt[3]{a} \times \sqrt[3]{b^5} + \sqrt[3]{b^5} = a^2\sqrt[3]{a} + a^2 \times \sqrt[3]{b} + a\sqrt[3]{a} \times \sqrt[3]{b^2} + ab + b\sqrt[3]{a} \times \sqrt[3]{b} + b \times \sqrt[3]{b^2}$, which multiplied by the $\sqrt[3]{a} - \sqrt[3]{b}$, gives $a^n - b^{\frac{nl}{m}} = a^3 - b^3$.

§ 122. By theſe Theorems any binomial ſurd whatſoever being given, you may find a ſurd which multiplied by it ſhall give a rational product.

Suppoſe that a binomial ſurd was to be divided by another, as $\sqrt[5]{20} + \sqrt[5]{12}$, by $\sqrt[5]{5} - \sqrt[5]{3}$, the





If any binomial furd is propoſed
umbers have different indices, le
d *l*, and take *n* equal to the leaſt in-
· that is meaſured by *m* and by $\frac{n}{l}$;
$^{n-2m}b^{2l} + a^{n-3m}b^{3l} \mp a^{n-4m}b^{4l}$, &c.
ompound furd, which multiplied
ed $a^m \pm b^l$ ſhall give a rational pro-
$\sqrt[s]{a} - \sqrt[s]{b}$ being given, ſuppoſe
and $\frac{m}{l} = \frac{s}{s}$, therefore you have
$^n + a^{n-2m}b^{2l} + a^{n-3m}b^{3l} + a^{n-4m}b^{4l}$
$+ a^{3-\frac{3}{s}}b^{\frac{3}{s}} + a^{3-\frac{2}{s}}b^{\frac{2}{s}} + a^{3-\frac{1}{s}}b^{\frac{1}{s}}$ +
$^{\frac{s}{s}} = a^{\frac{3}{s}} + a^{\frac{2}{s}}b^{\frac{1}{s}} + a^{\frac{1}{s}}b^{\frac{2}{s}} + ab^{\frac{3}{s}}$ +
$\sqrt[s]{a^3} + a^2 \times \sqrt[s]{b} + \sqrt[s]{a^1} \times \sqrt[s]{b^2}$
$\sqrt[s]{b^4} + \sqrt[s]{b^5} = a^2\sqrt[s]{a} + a^1 \times \sqrt[s]{b}$
$^{\frac{3}{s}} + ab + b\sqrt[s]{a} \times \sqrt[s]{b} + b^2 \times \sqrt[s]{b^1}$,
ied by the $\sqrt[s]{a} - \sqrt[s]{b}$, gives
$- b^s$.

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a binomial furd was to be di-
, as $\sqrt[s]{20} + \sqrt[s]{12}$, by $\sqrt[s]{5} - \sqrt[s]{3}$,
the



the quotient may be expreſſed by $\frac{\sqrt{20}+\sqrt{12}}{\sqrt{5}-\sqrt{3}}$. But it may be expreſſed in a more ſimple form by *multiplying both numerator and denominator by that furd which multiplied into the denominator gives a rational product.* Thus $\frac{\sqrt{20}+\sqrt{12}}{\sqrt{5}-\sqrt{3}} =$
$\frac{\sqrt{20}+\sqrt{12}}{\sqrt{5}-\sqrt{3}} \times \frac{\sqrt{5}+\sqrt{3}}{\sqrt{5}+\sqrt{3}} = \frac{\sqrt{100}+2\sqrt{60}+6}{5-3}$
$= \frac{16+2\sqrt{60}}{2} = 8 + 2\sqrt{15}$.

§ 123. In general, when any quantity is divided by a binomial furd, as $a^m \pm b^l$, where *m* and *l* repreſent any fractions whatſoever, *take n the leaſt integer number that is meaſured by m and* $\frac{m}{l}$, *multiply both numerator and denominator by* $a^{n-m} + a^{n-2m}b^l + a^{n-3m}b^{2l}$, &c. *and the denominator of the product will become rational, and equal to* $a^n - b^{\frac{nl}{m}}$; *then divide all the members of the numerator by this rational quantity, and the quote ariſing will be that of the propoſed quantity divided by the binomial furd, expreſſed in its leaſt terms.*

Thus $\frac{3}{\sqrt{5}-\sqrt{2}} = \frac{3\sqrt{5}+3\sqrt{2}}{3} = \sqrt{5}+\sqrt{2}$;

$\frac{\sqrt{6}}{\sqrt{7}-\sqrt{3}} = \frac{\sqrt{42}+\sqrt{18}}{4}$; $\frac{1}{\sqrt[3]{4}-\sqrt[3]{2}} \times \frac{\sqrt[3]{20}}{\sqrt[3]{4}-\sqrt[3]{2}}$
$= \frac{\sqrt[3]{16}+2+\sqrt[3]{4}}{\sqrt[3]{16}+2+\sqrt[3]{4}} = \frac{\sqrt[3]{20}}{\sqrt[3]{4}-\sqrt[3]{2}} \times \frac{2\sqrt[3]{2}+2+\sqrt[3]{4}}{2\sqrt[3]{2}+2+\sqrt[3]{4}}$
=

$= \frac{2\sqrt[3]{40} + 2\sqrt[3]{20} + \sqrt[3]{80}}{2} = 2\sqrt[3]{5} + \sqrt[3]{20} + \sqrt[3]{10}$ :

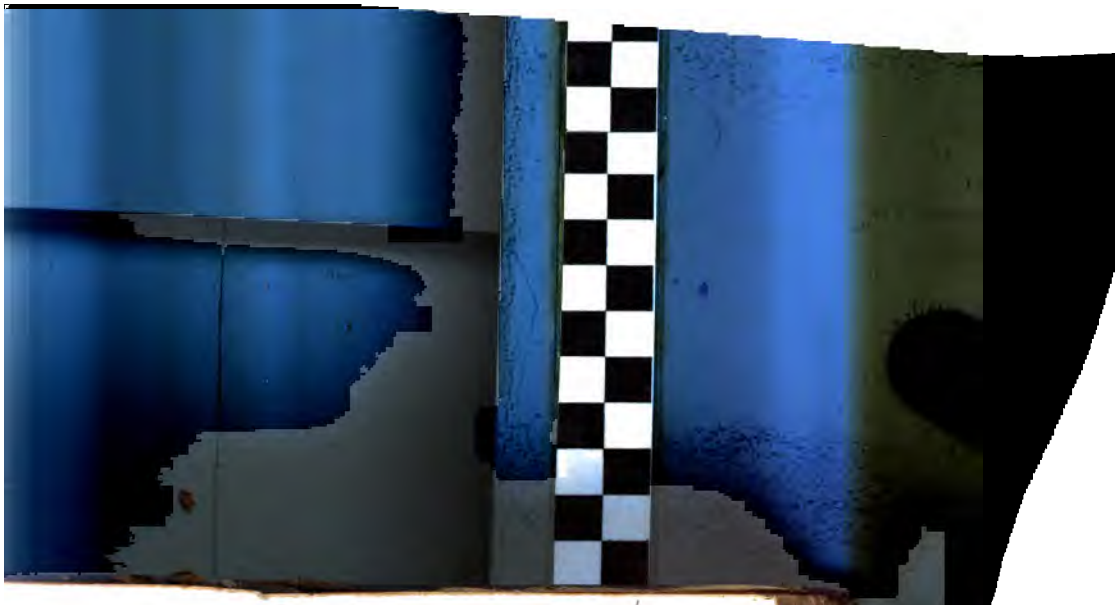
Alſo $\frac{\sqrt[3]{10}}{\sqrt[3]{2} - \sqrt[3]{3}}$ = (becauſe $m = \frac{1}{3}$, $l = \frac{1}{3}$, $n = 3$, and $a^n - b^{\frac{n}{m}} = 8 - 9 = -1$) =

$$\frac{4\sqrt[3]{20} + 4\sqrt[3]{10} \times \sqrt[3]{3} + 2\sqrt[3]{20} \times \sqrt[3]{9} + 6\sqrt[3]{10} + 3\sqrt[3]{20} \times \sqrt[3]{3} + 3\sqrt[3]{10} \times \sqrt[3]{9}}{-1}$$

$= -8\sqrt[3]{5} - 4\sqrt[3]{10} \times \sqrt[3]{3} - 8\sqrt[3]{5} \times \sqrt[3]{9} -$
$6\sqrt[3]{10} - 6 \times \sqrt[3]{5} \times \sqrt[3]{3} - 3\sqrt[3]{10} \times \sqrt[3]{9}$.

§ 124. When the ſquare root of a ſurd is required, it may be found nearly *by extracting the root of a rational quantity that approximates to its value*. Thus to find the ſquare root of $3 + 2\sqrt{2}$, we firſt calculate $\sqrt{2} = 1,41421$, and therefore $3 + 2\sqrt{2} = 5,82842$, whoſe root is found to be nearly 2,41421: ſo that $\sqrt{3 + 2\sqrt{2}}$ is nearly 2,41421. But ſometimes we may be able to expreſs the roots of ſurds exactly by other ſurds; as in this example the ſquare root of $3 + 2\sqrt{2}$ is $1 + \sqrt{2}$, for $\sqrt{1 + \sqrt{2}} \times \sqrt{1 + \sqrt{2}} = 1 + 2\sqrt{2} + 2 = 3 + 2\sqrt{2}$.

In order to know when and how this may be found, let us ſuppoſe that $x + y$ is a binomial ſurd, whoſe ſquare will be $x^2 + y^2 + 2xy$: If $x$ and $y$ are quadratic ſurds, then $x^2 + y^2$ will be rational, and $2xy$ irrational; ſo that $2xy$ ſhall





$\frac{\sqrt[3]{20}+\sqrt[3]{80}}{4} = 2\sqrt[3]{5}+\sqrt[3]{20}+\sqrt[3]{10}$

$= (\text{because } m = \frac{1}{3}, l = \frac{1}{3}, n \ldots$

$= 8-9 = -1) =$

$\frac{\ldots+2\sqrt{20}\times\sqrt[3]{9}+6\sqrt{10}+3\sqrt{20}\times\sqrt[3]{3}+\ldots}{-1}$

$4\sqrt{10}\times\sqrt[3]{3}-8\sqrt{5}\times\sqrt[3]{9}-$

$\sqrt{5}\times\sqrt[3]{3}-3\sqrt{10}\times\sqrt[3]{9}.$

n the ſquare root of a ſurd is re-
be found nearly *by extracting the*
*l quantity that approximates to it*
find the ſquare root of $3+2\sqrt{2}$
e $\sqrt{2}=1,41421$, and therefore
842, whoſe root is found to be

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ſometimes we may be able to
of ſurds exactly by other ſurds;
le the ſquare root of $3+2\sqrt{2}$
$+\sqrt{2}\times 1+\sqrt{2} = 1+2\sqrt{2}$

w when and how this may be
oſe that $x+y$ is a binomial
will be $x^2+y^2+2xy$. If $x$
tie ſurds, then $x^2+y^2$ will
$2xy$ irrational; ſo that $2xy$
ſhall



ſhall always be leſs than $x^2+y^2$, becauſe the difference is $x^2+y^2-2xy = \overline{x-y}^2$, which is always poſitive. Suppoſe that a propoſed ſurd conſiſting of a rational part A, and an irrational part B, coincides with this, then $x^2+y^2 = A$ and $xy = \frac{1}{2}B$: Therefore by what was ſaid of Equations, *Chap.* 13th,

$$y^2 = A - x^2 = \frac{B^2}{4x^2}, \text{ and therefore}$$

$$Ax^2 - x^4 = \frac{B^2}{4}, \text{ and } x^4 - Ax^2 + \frac{B^2}{4} = 0;$$

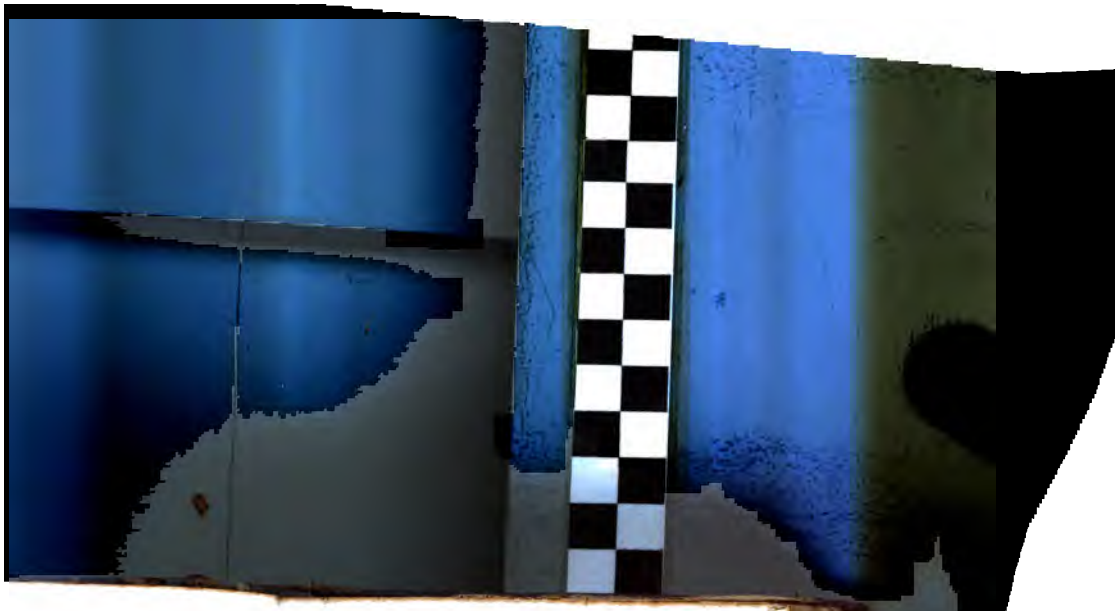
from whence we have $x^2 = \frac{A+\sqrt{A^2-B^2}}{2}$ and $y^2 = \frac{A-\sqrt{A^2-B^2}}{2}$. Therefore when a quantity partly rational and partly irrational is propoſed to have its root extracted, *call the rational part* A, *the irrational* B, *and the ſquare of the greateſt member of the root ſhall be* $\frac{A+\sqrt{A^2-B^2}}{2}$, *and the ſquare of the leſſer part ſhall be* $\frac{A-\sqrt{A^2-B^2}}{2}$. And as often as the ſquare root of $A^2-B^2$ can be extracted, the ſquare root of the propoſed binomial ſurd may be expreſſed itſelf as a binomial ſurd. For example, if $3+2\sqrt{2}$ is propoſed, then $A = 3$, $B = 2\sqrt{2}$, and $A^2-B^2 = 9-8 = 1$. Therefore $x^2 = \frac{A+\sqrt{A^2-B^2}}{2} = 2$, and $y^2 = \frac{A-\sqrt{A^2-B^2}}{2} = 1$. Therefore $x+y = 1+\sqrt{2}$.

To find the ſquare root of $-1\sqrt{-8}$, ſuppoſe $A=-1$, $B=\sqrt{-8}$, ſo that $A^2-B^2=9$, and $\frac{A+\sqrt{A^2-B^2}}{2}=\frac{-1+3}{2}=1$, and $\frac{A-\sqrt{A^2-B^2}}{2}=\frac{-1-3}{2}=-2$, therefore the root required is $1+\sqrt{-2}$.

§ 125. But though $x$ and $y$ are not quadratic ſurds or roots of integers, if they are the roots of like ſurds, as if they are equal to $\sqrt{m\sqrt{z}}$ and $\sqrt{n\sqrt{z}}$, where $m$ and $n$ are integers, then $A=\overline{m+n}\times\sqrt{z}$ and $\frac{1}{2}B=\sqrt{mnz}$; $A^2-B^2=\overline{m-n}^2\times z$, and $x^2=\frac{A+\sqrt{A^2-B^2}}{2}=\frac{\overline{m+n}\times z+\overline{m-n}\times z}{2}=m\sqrt{z}$, $y^2=\frac{A-\sqrt{A^2-B^2}}{2}=n\sqrt{z}$, and $x+y=\sqrt{m\sqrt{z}}+\sqrt{n\sqrt{z}}$. The part A here eaſily diſtinguiſhes itſelf from B by its being greater.

§ 126. If $x$ and $y$ are equal to $\sqrt{m\sqrt{z}}$ and $\sqrt{n\sqrt{t}}$, then $x^2+2xy+y^2=m\sqrt{z}+n\sqrt{t}+2\sqrt{mn\sqrt{zt}}$. So that if $z$ or $t$ be not multiples one of the other, or of ſome number that meaſures them both by a ſquare number, then will A itſelf be a binomial.

§ 127. Let $x+y+z$ expreſs any trinomial ſurd, its ſquare $x^2+y^2+z^2+2xy+2xz+2yz$ may be ſuppoſed equal to $A+B$ as before. But rather





the ſquare root of $-1\sqrt{-8}$, for
$\cdot 1$, $B = \sqrt{-8}$, ſo that $A^2 - B^2 =$
$\frac{-1+3}{2} = 1$, and $\frac{A-\sqrt{A^2-B^2}}{2}$
$-2$, therefore the root required
2.

though $x$ and $y$ are not quadratic
of integers, if they are the root
as if they are equal to $\sqrt{n}$
where $m$ and $n$ are integers, then
$\sqrt{z}$ and $\frac{1}{2}B = \sqrt[3]{mnz}$; $A^2 - B^2 =$
and $x^2 = \frac{A + \sqrt{A^2 - B^2}}{2} =$
$\frac{x \times z}{} = m\sqrt{z}, y^2 = \frac{A-\sqrt{A^2-B^2}}{2}$
$+ y = \sqrt{m\sqrt{z}} + \sqrt{n\sqrt{2}}$. The
ily diſtinguiſhes itſelf from B by
r.

and $y$ are equal to $\sqrt{m\sqrt{z}}$ and
$+ 2xy + y^2 = m\sqrt{z} + n\sqrt{t} +$
that if $z$ or $t$ be not multiples
or of ſome number that mea-
by a ſquare number, then will
omial.
$+ y + z$ expreſs any trinomial
$^2 + y^2 + z^2 + 2xy + 2xz + 2yz$
equal to $A + B$ as before, But
rather



rather multiply any two radicals as $2xy$ by $2xz$, and divide by the third $2yz$, which gives the quotient $2x^2$ rational, and double the ſquare of the ſurd $x$ required. The ſame rule ſerves when there are four quantities, $x^2 + y^2 + z^2 + s^2 + 2xy + 2xs + 2xz + 2yz + 2ys + 2zs$, multiply $2xy$ by $2xs$, and the product $4x^2sy$ divided by $2y$ gives $2x^2$ a rational quotient, half the ſquare of $2x$. In like manner $2xy \times 2yz = 4y^2xz$, which divided by $2xz$ another member gives $2y^2$, a rational quote, the half of the ſquare of $2y$. In the ſame manner $z$ and $s$ may be found; and their ſum $x + y + z + s$, the ſquare root of the ſeptinomial $x^2 + y^2 + z^2 + s^2 + 2xy + 2xs + 2xz + 2yz + 2ys$, diſcovered.

For example, to find the ſquare root of $10 + \sqrt{24} + \sqrt{40} + \sqrt{60}$; I try $\frac{\sqrt{24} \times \sqrt{40}}{\sqrt{60}}$, which I find to be $\sqrt{16} = 4$, the half of the ſquare root of the double of which, *viz.* $\frac{1}{2} \times \sqrt{8} = \sqrt{2}$, is one member of the ſquare root required; next $\frac{\sqrt{24} \times \sqrt{60}}{\sqrt{40}} = 6$, the half of the ſquare root of the double of which is $\sqrt{3}$, another member of the root required; laſtly, $\frac{\sqrt{40} \times \sqrt{60}}{\sqrt{24}} = 10$, which gives $\sqrt{5}$ for the third member of the root required: From which we conclude that the ſquare root of $10 + \sqrt{24} + \sqrt{40} + 60$ is $\sqrt{2} + \sqrt{3} + \sqrt{5}$; and trying you find it ſucceeds, ſince

multiplied by itſelf it gives the propoſed quadrinomial.

§ 127 For extracting the higher roots of a binomial, whoſe two members being ſquared are commenſurable numbers, there is the following

RULE.

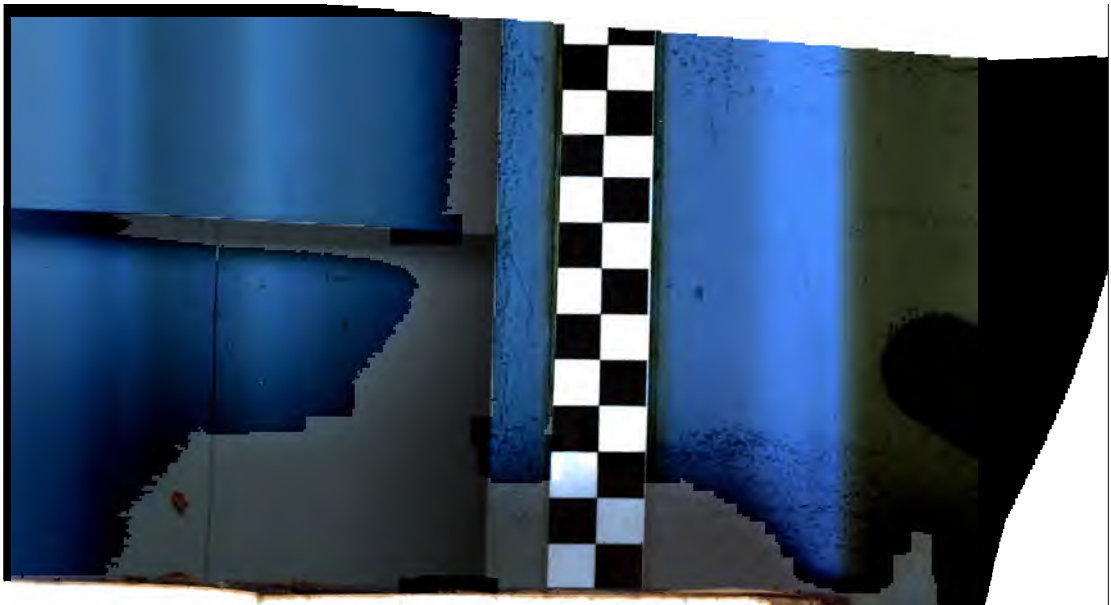
* "*Let the quantity be* $A \pm B$, *whereof* A *is the greater part, and* c *the exponent of the root required. Seek the leaſt number* n *whoſe power* $n^c$ *is diviſible by* $AA - BB$, *the quotient being* Q. *Compute* $\sqrt[c]{\overline{A+B} \times \sqrt{Q}}$ *in the neareſt integer number, which ſuppoſe to be* r. *Divide* $A\sqrt{Q}$ *by its greateſt rational diviſor, and let the quotient be* s, *and let* $\frac{r+\frac{n}{r}}{2s}$, *in the neareſt integer number, be* t, *ſo ſhall the root required be* $\frac{tt \pm \sqrt{t^2 t^2 - n}}{\sqrt[2c]{Q}}$, *if the* c *root of* $A \pm B$ *can be extracted.*

EXAMPLE I.

Thus to find the cube root of $\sqrt{968} + 25$, we have $A^2 - B^2 = 343$, whoſe diviſors are 7, 7, 7, whence $n = 7$, and $Q = 1$. Further, $\overline{A+B} \times \sqrt{Q}$, that is, $\sqrt{968}+25$ is a little more

* Arithm. Univerſal. p. 59.

than





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extracting the higher roots of i
oſe two members being ſquare
rable numbers, there is the fol

RULE.

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part, and c the exponent of the
Seek the leaſt number n which
diviſible by $AA - BB$, the qu

Compute $\sqrt[c]{A+B\times\sqrt{Q}}$ in the
number, which ſuppoſe to be
by its greateſt rational diviſor,

otient be s, and let $\frac{r+\frac{n}{r}}{2s}$, in the
number, be t, ſo ſhall the roo
$= \frac{\sqrt{t^2s^2-n}}{\sqrt[2c]{Q}}$, if the c root of
racted.

MPLE I.

cube root of $\sqrt{968}+25$,
$= 343$, whoſe diviſors are
$= 7$, and $Q = 1$. Further,
, $\sqrt{968}+25$ is a little more
Univerſal. p 59.

than



than 56, whoſe neareſt cube root is 4. Wherefore $r=4$. Again, dividing $\sqrt{968}$ by its greateſt rational diviſor, we have $A\sqrt{Q}=22\sqrt{2}$, and the radical part $\sqrt{2}=s$, and $\frac{r+\frac{n}{r}}{2s}$, or $\frac{5}{2\sqrt{2}}$, in the neareſt integers, is $2=t$. And laſtly, $ts=2\sqrt{2}$, $\sqrt{t^2s^2-n}=1$, and $\sqrt[2c]{Q}=\sqrt[6]{1}=1$. Whence $2\sqrt{2}+1$ is the root, whoſe cube, upon trial, I find to be $\sqrt{968}+25$.

EXAMPLE II.

To find the cube root of $68-\sqrt{4374}$; we have $A^2-B^2=250$, whoſe diviſors are 5, 5, 5, 2. Thence $n=5\times 2=10$, and $Q=4$, and $\sqrt[c]{A+B\times\sqrt{Q}}$ or $\sqrt[3]{68+\sqrt{4374}\times 2}$ is nearly $7=r$; again, $A\sqrt{Q}$ or $68\times\sqrt{4}=136\times\sqrt{1}$, that is, $s=1$, and $\frac{r+\frac{n}{r}}{2s}$, or $\frac{7+\frac{10}{7}}{2}$, is nearly $=4=t$. Therefore $ts=4$, $\sqrt{t^2s^2-n}=\sqrt{6}$, and $\sqrt[2c]{Q}=\sqrt[6]{4}=\sqrt[3]{2}$, whence the root to be tried is $\frac{4-\sqrt{6}}{\sqrt[3]{2}}$.

EXAMPLE III.

Suppoſe the fifth root of $29\sqrt{6}+41\sqrt{3}$ is demanded, $A^2-B^2=3$, and $n=3$; $Q=81$, $r=5$,

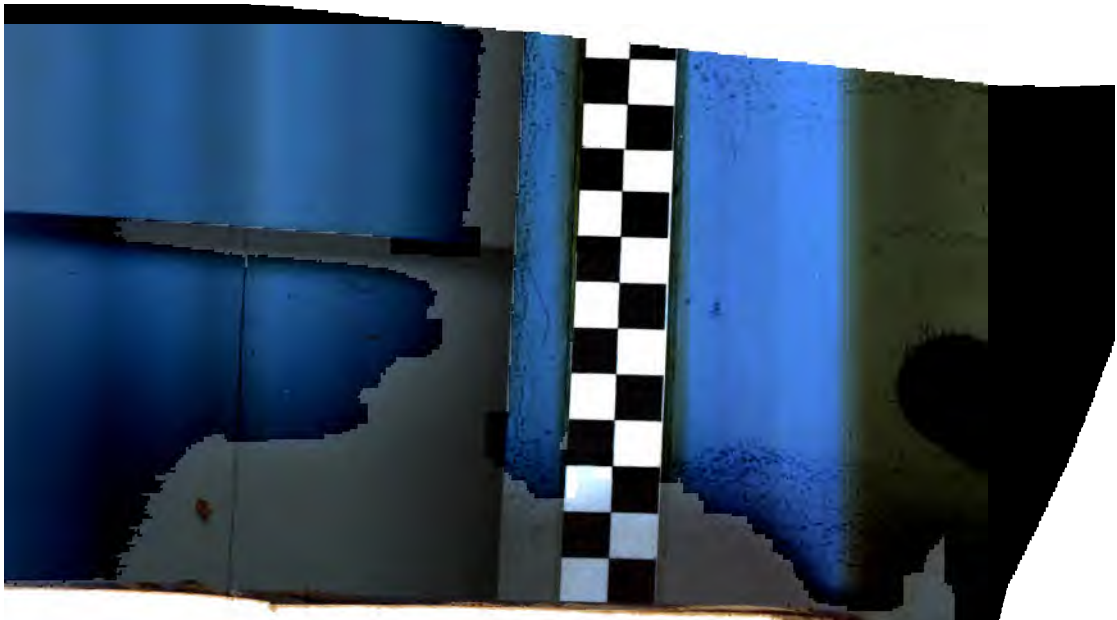
$r=5$, $s=\sqrt{6}$, $t=1$, $ts=\sqrt{6}$, $\sqrt{1^2 3^2 - n}=\sqrt{3}$, and $\sqrt[2c]{Q}=\sqrt[10]{81}=\sqrt[5]{9}$. And therefore trial is to be made with $\frac{\sqrt{6}+\sqrt{3}}{\sqrt[5]{9}}$.

In these operations, if the quantity is a fraction, or if its parts have a common divisor, you are to extract the root of the *numerator* and *denominator*, or of the *factors* separately. Thus to extract the cube root of $\sqrt{242}-12\frac{1}{2}$, this reduced to a common denominator is $\frac{\sqrt{968}-25}{2}$. And the roots of the numerator and denominator, separately found, give the root $\frac{2\sqrt{2}-1}{\sqrt[3]{2}}$. And if you seek any root of $\sqrt[3]{3993}+\sqrt[5]{17578125}$, divide its parts by the common divisor $\sqrt[3]{3}$, and the quotient being $11+\sqrt{125}$, the root of the quantity proposed will be found by taking the roots of $\sqrt[3]{3}$ and of $11+\sqrt{125}$, and multiplying them into each other.

§ 128. The ground of this Rule may be explained from the following

## THEOREM

*Let the sum or difference of two quantities x and y be raised to a power whose exponent is c, and*





6, $t=1$, $ts=\sqrt{6}$, $\sqrt{t^2s^2-n}=\sqrt[5]{3}$

$81=\sqrt[5]{9}$. And therefore trial is

th $\frac{\sqrt{6}+\sqrt{3}}{\sqrt[5]{9}}$.

rations, if the quantity is a fra-

parts have a common divisor, you

he root of the *numerator* and de-

f the *factors* separately. Thus

cube root of $\sqrt{24^2-11^2}$

o a common denominator is

nd the roots of the numerator

r, separately found, give the

And if you seek any root of

$78125$, divide its parts by the

$\sqrt[3]{3}$, and the quotient being

root of the quantity proposed

taking the roots of $\sqrt[3]{3}$ and

multiplying them into each

nd of this Rule may be ex-

llowing

EOREM

*ifference of two quantities x*

*power whose exponent is c,*

*and*



*and let the 1st, 3d, 5th, 7th, &c. terms of that power, collected into one sum, be called* A, *and the rest of the terms, in the even places, call* B; *the difference of the squares of* A *and* B *shall be equal to the difference of the squares of x and y raised to the same power c.*

For the terms in the $c$ power of $x+y$ (writing for their coefficients, respectively, 1, $c$, $d$, $e$, &c. are

$x^c+cx^{c-1}y+dx^{c-2}y^2+ex^{c-3}y^3+$, &c. $=A+B$,

and the same power of $x-y$ (changing the signs in the even places) is

$x^c-cx^{c-1}y+dx^{c-2}y^2-ex^{c-3}y^3+$, &c. $=A-B$,

and therefore $\overline{x+y}^c\times\overline{x-y}^c=\overline{A+B}\times\overline{A-B}$

$=A^2-B^2$ $(=\overline{x+y\times x-y}^1)=\overline{x^2-y^2}^c$.

Q. E. D.

Let one, or both, of the quantities $x$, $y$, be a quadratic *surd*, that is, let $x+y$, the $c$ root of the proposed binomial $A+B$ belong to one of these forms, $p+l\sqrt{q}$, $k\sqrt{p+q}$, or $k\sqrt{p+l\sqrt{q}}$. And it follows,

1. If $x+y=p+l\sqrt{q}$, that, $c$ being any whole number, A, the sum of the *odd* terms, will be a rational number; and B, the sum of the terms in the *even* places, each of which involves an *odd* power of $y$ will be a rational number multiplied into the quadratic surd $\sqrt{q}$.

2. Let $c$, the exponent of the root fought, be an odd number, as we may always suppose

it, becauſe if it is even, it may be halved by the extraction of the ſquare root, till it becomes odd; and let $x+y=k\sqrt{p}+q$. Then A will involve the ſurd $\sqrt{p}$, and B will be rational.

3. But if both members of the root are irrational ($x+y=k\sqrt{p}+l\sqrt{q}$) A and B are both irrational, the one involving $\sqrt{p}$, and the other the ſurd $\sqrt{q}$.

And in all theſe caſes, it is eaſily ſeen that when $x$ is greater than $y$, A will be greater than B.

§ 129. From this compoſition of the binomial A+B, we are led to its reſolution, as in the foregoing rule, by theſe ſteps.

I.

When A is *rational*, and $A^2-B^2$ is a perfect $c$ power.

1. By the *Theorem*, $A^2-B^2=\overline{x^2-y^2}^c$ *accurately*; and therefore extracting the $c$ root of $A^2-B^2$ it will be $x^2-y^2$. Call this root $n$.

2. Extract in the neareſt integer, the $c$ root of A+B, it will be (*nearly*) $x+y$. Which put $=r$.

3. Divide $x^2-y^2$ $(=n)$ by $x+y$ $(=r)$ the quotient is (*nearly*) $x-y$; and the ſum of the diviſor and quotient is (*more nearly*) $2x$; that is, if an integer value of $x$ is to be found, it will be the neareſt to $\frac{r+\frac{n}{r}}{2}$.

4.

f it is even, it may be halved by th
the ſquare root, till it become
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are led to its reſolution, as it
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I.

'ional, and $A^2-B^2$ is a per-

'orem, $A^2-B^2=\overline{x^2-y^2}^{\epsilon}$ ext
fore extracting the $\epsilon$ root of
$x^2-y^2$. Call this root $n$.
ıe neareſt integer, the $\epsilon$ root
be (*nearly*) $x+y$. Which

$^2$ $(=n)$ by $x+y$ $(=r)$ the
$-y$; and the ſum of the
is (*more nearly*) $ax$; that is,
f $x$ is to be found, it will

4.



4. $x^2-\overline{x^2-y^2}^{\epsilon}=y^2$; or, $\overline{\frac{r+\frac{n}{r}}{2}}^{\epsilon}-n=y^2$;

whence $y=\sqrt{\overline{\frac{r+\frac{n}{r}}{2}}^{\epsilon}-n}$, and therefore, putting $t=\frac{r+\frac{n}{r}}{2}$, the root ſought $x+y=t+\sqrt{t^2-n}$; the ſame expreſſion as in the rule, when $Q=1$, $s=1$, that is, when $A^2-B^2$ is a perfect $\epsilon$ power, and the greater member A is rational.

II.

When A is *irrational*, and $Q=1$.

By the ſame proceſs, $x=\frac{r+\frac{n}{r}}{2}$ $(=T)$ and $y=\sqrt{T^2-n}$. But ſeeing A is ſuppoſed irrational, and $\epsilon$ an odd number, $x$ will be irrational likewiſe; and they will both involve the ſame irreducible ſurd $\sqrt{p}$, or $s$, which is found by dividing A by its greateſt rational diviſor. Write therefore for $x$ or T, its value $t\times s$, and $x+y=ts+\sqrt{t^2s^2-n}$.

III.

If the $\epsilon$ root of $A^2-B^2$ cannot be taken, multiply $A^2-B^2$ by a number $Q_2$ ſuch as that the product may be the (leaſt) perfect $\epsilon$ power $n^{\epsilon}$ $(=A^2Q_2-B^2Q_2)$. And now (inſtead of A+

2

A + B) extract the $c$ root of $\overline{A+B} \times \sqrt{Q}$, which, found as above, will be $ts + \sqrt{t^2s^2 - n}$; and consequently the $c$ root of A + B will be $ts + \sqrt{t^2s^2 - n}$, divided by the $c$ root of $\sqrt{Q}$, that is, $\frac{ts + \sqrt{t^2s^2 - n}}{\sqrt[2c]{Q}}$.

It is required in the rule that *a perfect c power* ($n^c$) *be found which shall be a multiple of* $A^2 - B^2$ *by the whole number* Q. To find this power, let the given number $A^2 - B^2$ be represented by the product $a^m b^e d^f$; whose single divisors let be $a, a, a, \ldots b, b, b, \ldots d, f$; and the product of these divisors raised to the power $c$, which is $a^{mc} b^{ec} d^{fc}$, divided by $a^m b^e d^f$ will give the quotient $a^{mc-m} b^{ec-e} d^{fc-f} = Q$, a whole number, provided some index, as $m$ or $p$, be not greater than $c$. If it is, take, instead of the single divisor $a$ or $b$, $a^2$ or $b^2$, $a^3$ or $b^3$, &c. till there be no negative index in the quotient; that is, till Q be a whole number.

§ 130. We may add the following remarks

1. If the residual A − B is given, it is evident from its genesis by involution, that the same rule gives its root $x - y$.

2. The extracting the $c$ root of A + B, or of $A + B \times \sqrt{Q}$, in the nearest integer, neglecting the fractional part, will always give $x + y$ such, that the value of $x$ which results in the operation shall not differ from its true value

xtract the $c$ root of $\overline{A+B} \times \sqrt{}$
nd as above, will be $u + \sqrt{t^2 - 1}$
quently the $c$ root of $A+B$ will
$- n$, divided by the $c$ root of $\sqrt{}$
$\sqrt{t^2 - 1 - n}$
$2c$
$\sqrt{Q}$.

ired in the rule that *a perfect power which shall be a multiple of the whole number* Q. To find this power number $A^2 - B^2$ be reprefent uct $a^m b^n d^f$; whofe fingle divifo $a, \ldots b, b, b, \ldots d, f$; a of theſe divifors raiſed to the powe $b^n d^f$, divided by $a^m b^n d f$ will giv $a^{c-m} b^{c-n} d^{c-f} = Q$, a whol rided ſome index, as $m$ or $p$, le an $c$. If it is, take, inſtead of its $a$ or $b$, $a^2$ or $b^2$, $a^3$ or $b^3$, &c o negative index in the quotient, be a whole number.

may add the following remark dual $A - B$ is given, it is eaſ geneſis by involution, that the its root $x - y$.

ſting the $c$ root of $A+B$, or of in the neareſt integer, neglect ul part, will always give $x+y$ value of $x$ which reſults in the ot differ from its true value by unity;

unity; that is, it ſhall be the true integer value ſought.

For $f$ being ſome proper fraction, let $x + y \pm f$ be the accurate value of $\sqrt[c]{\overline{A+B} \times \sqrt{Q}}$, and let the quotient of $x^2 - y^2$ divided by it be $x - y \mp g$, then, the ſum of the diviſor and quotient being $2x \pm f \mp g$, if our reckoning the fractional part could make a difference of unity in the value of $x$, it would follow that $f - g$ or $g - f = 2$. Which is abſurd, $g$, as well as $f$, being a proper fraction.

3. If both A and B are irrational; or, if the leſſer of the two members is rational, no root denominated by an even number can be found.

4. When the greater member is rational, and the exponent $c$ is an even number, it is ambiguous whether the greater member of the root is rational or ſurd. And though a root in the form of $p + l\sqrt{q}$ is not found, yet a root in the form of $k\sqrt{p} + q$, or, that failing, in the form $k\sqrt{p} + l\sqrt{q}$ may be obtained.

If we look for a root $k\sqrt{p} + q$, we are now to ſubtract $x - y$ from $x + y$, and half the remainder will give $y$ (or $q$) the rational part. And to $x^2 - y^2$ $(= n)$ adding $y^2$, the ſum will be $x^2$. So that $y = \frac{r - \frac{n}{r}}{2}$, and $x = \sqrt{\left(\frac{r - \frac{n}{r}}{2}\right)^2 + n}$; the expreſſions being the ſame as when $c$ is odd,

with the ſign of $n$ changed. If this does not ſucceed, and a prime number ſtands under the radical ſign, no farther trial need be made.

But if a compoſite number ſtands under the radical ſign, the root may poſſibly belong to the form $k\sqrt{p}+l\sqrt{q}$; and that compoſite number being $p\times q$, ſince $k^2p-l^2q=n$, and $k\sqrt{p}=x$, the numbers $k$, $l$, may be ſought for in the neareſt integers, and trial made with $k\sqrt{p}+l\sqrt{q}$; as in this

## EXAMPLE.

*To find the fourth root of* $49849-2895\sqrt{224}$.

The 4th root of $A^2-B^2$ is $157=x^2-y^2=n$, and the 4th root of $A-B$, that is, $x-y=r=9$ *nearly*: and $\frac{n}{r}=\frac{157}{9}=17$ *nearly*. Whence $x=\frac{9+17}{2}=13$. But now the leaſt radical factor in B being $\sqrt{14}=\sqrt{7\times 2}$, I put $13\ (=x)=k\sqrt{7}$, and $k$ in the neareſt integer $=5$. Again $k^2p-l^2q=n=175-l^2\times 2=157$; that is, $l^2\times 2=18$, and $l=3$; which gives the root $5\sqrt{7}-3\sqrt{2}$.

In this manner the even roots may be ſought immediately. But to avoid ambiguity and needleſs trouble, it is better firſt to depreſs them by extracting the ſquare root, as in § 124.

A SUP-

n of $n$ changed. If this does n
l a prime number ſtands under it
no farther trial need be made.
ompoſite number ſtands under it
the root may poſſibly belong t
$+l\sqrt{q}$; and that compoſite num
$q$, ſince $k^2p-l^2q=n$, and $k\sqrt{p}=$
$k$, $l$, may be ſought for in the
s, and trial made with $k\sqrt{p}+l\sqrt{q}$

EXAMPLE.

*urth root of* $49849-2895\sqrt{14}$

ot of $A^2-B^2$ is $157=x^2-y^2$
ot of $A-B$, that is, $x-y=$
$-\frac{157}{9}=17$ *nearly.* Whence

. But now the leaſt radical fa-

$\sqrt{14}=\sqrt{7\times 2}$, I put 13 (=
n the neareſt integer $=5$. H
$n=175-l^2\times 2=157$; that
and $l=3$; which gives the
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the even roots may be ſought
to avoid ambiguity and need-
better firſt to depreſs them by
are root, as in § 124.

A SUP-



# A SUPPLEMENT TO THIS CHAPTER

§ 131. THERE occur ſometimes, eſpecially in the reſolution of *cubic* equations by *Cardan*'s Rule (*Part.* II. § 79.) binomials of this form $A\pm B\sqrt{-q}$, whoſe cube roots muſt be found. To theſe the foregoing rule cannot be applied throughout, becauſe of the imaginary factor $\sqrt{-q}$. Yet if the root is expreſſible in rational numbers, the firſt ſtep of that rule will often lead us to it in a ſhort way, not merely tentative, the trials being confined to known limits.

For it being, univerſally, $\sqrt[6]{A^2-B^2q}=x^2-y^2$ and, in the preſent caſe, $\sqrt[3]{A^2+B^2q}(=x^2-y^2)=p^2+l^2\times q$; if we divide the part under the radical ſign by its greateſt rational diviſor, the quote is the imaginary ſurd $\sqrt{-q}$, and from $\sqrt[3]{A^2+B^2q}$, ſubtracting $p^2$, the ſquare of ſome diviſor of A, the remainder is $l^2\times q$, a known multiple of the ſquare of $l$ a diviſor of B.

That

That $p$ and $l$ are diviſors of A and B reſpectively is evident; for cubing $p+l\sqrt{-q}$, you find $A=p\times\overline{p^2-3l^2q}$, $B=l\times\overline{3p^2-l^2q}$. And the ſigns of $p$ and $l$ muſt be ſuch as will give the products of $p\times\overline{p^2-3l^2q}$, $l\times\overline{3p^2-l^2q}$ of the ſame ſigns as A and B reſpectively.

## EXAMPLE.

*To find the cube root of* $81+\sqrt{-2700}=81+30\sqrt{-3}$.

Here $A=81$, $B=30$, $q=3$; $\sqrt[3]{81\times81+2700}=21=p^3+l^2q$. Subtracting therefore from 21, the ſquare of $(p)\pm3$, which is a diviſor of A, there remains $(l^2\times q=)\ 2\times2\times3$. And $(l=)\ 2$ is a diviſor of 30. Laſtly, A $(=p\times\overline{p^2-3l^2q})$ being poſitive, and the factor $p^2-3l^2q$ negative, $p$ muſt have the negative ſign; and for the like reaſon $l=+2$. So that the root is $-3+2\sqrt{-3}$.

It will be ſhewn in the ſecond Part of this Treatiſe that "every cube or other power has as many roots, real and imaginary, as there are units in the exponent of the power;" particularly, that *unity* itſelf has the cube roots 1, $\frac{-1+\sqrt{-3}}{2}$, and $\frac{-1-\sqrt{-3}}{2}$. If therefore we would find the other two cube roots, in this example, ſeeing $z^1=z^1\times1$, and $\sqrt[3]{z^1}\times\sqrt[3]{1}=z$

(z¹





) and $l$ are divisors of A and B respe-
evident; for cubing $p+l\sqrt{-b}$,
$p\times\overline{p^2-3l^2q}$, $B=l\times\overline{3p^2-l^2q}$, &c.
$p$ and $l$ must be such as will give th
$p\times\overline{p^2-3l^2q}$, $l\times\overline{3p^2-l^2q}$ of th
as $A$ and $B$ respectively.

## EXAMPLE.

*be cube root of* $81+\sqrt{-2700}$
$-3$.

$81, B=30, q=3$; $\sqrt[3]{81\times81+270}$
$q$. Subtracting therefore from
$(p)\pm3$, which is a divisor of A
$(l^2\times q=)\ 2\times2\times3$. And ($l=$)
f 30. Lastly, A ($=p\times\overline{p^2-3l^2q}$
, and the factor $p^2-3l^2q$ nega-
ave the negative sign; and for th
$=+2$. So that the root is $-$

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every cube or other power has
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e other two cube roots, in this
$z^3=z^3\times1$, and $\sqrt[3]{z^3}\times\sqrt[3]{1}=z$
($z^3$



($z^3$ representing any cube whatever, and $z$ any of its roots) we are to multiply $-3+2\sqrt{-3}$, the root already found, by $-\frac{3}{2}+\frac{1}{2}\sqrt{-3}$, and by $-\frac{1}{2}-\frac{1}{2}\sqrt{-3}$, and the products $-\frac{1}{2}-\frac{5}{2}\sqrt{-3}$, and $\frac{9}{4}+\frac{1}{4}\sqrt{-3}$ will be the root required.

Or, because the denominator of the imaginary roots of unity is 2, taking $p=\frac{3}{2}$, one half of a divisor of A, we have $21-\frac{9}{2}=\frac{7\cdot3}{2}=\frac{3^2}{2^2}\times3=l^2q$, that is $l=\frac{3}{2}$; and $p^2-3l^2q$ as well as $3p^2-l^2q$ being negative, both $p$ and $l$ must be negative, and the root is $-\frac{3}{2}-\frac{3}{2}\sqrt{-3}$. Again take $p=\frac{9}{4}$, and you shall find $l=+\frac{1}{4}$; so the remaining root is $\frac{9}{4}+\frac{1}{4}\sqrt{-3}$, as before.

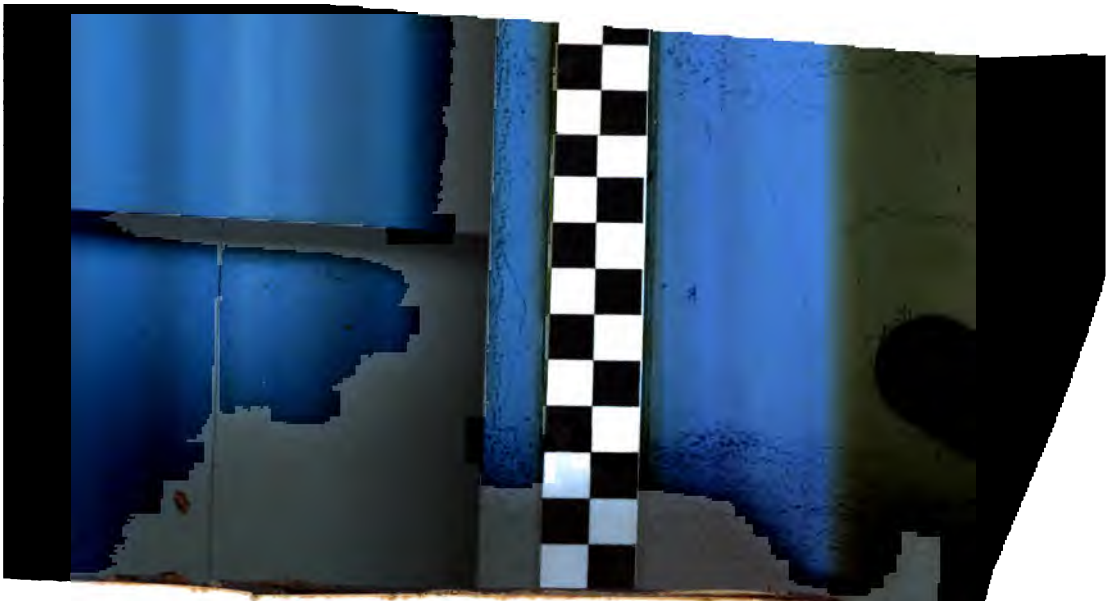
We may here observe that the operation ought to be abridged, where it can be done, by dividing the given binomial by the greatest cube that it contains; and finding the root of the quotient; which multiplied by the root of the cube by which you divided, will give the root required. Thus, in the foregoing Example, $81+\sqrt{-2700}=27\times3+\sqrt{-\frac{2700}{27}}$, and the roots of $3+\sqrt{-\frac{2700}{27}}$ being now, more easily, found to be $-1+2\sqrt{-\frac{1}{3}}$, $-\frac{1}{2}-\frac{3}{2}\sqrt{-\frac{1}{3}}$, and $\frac{3}{2}+\frac{1}{2}\sqrt{-\frac{1}{3}}$, these multiplied by 3, the cube root of 27, give the roots required the same as above.

"If the coefficient of the imaginary member of the binomial has a contrary sign, the roots will be the same, with the signs of the imaginary

imaginary parts changed." Thus the cube roots of $81-\sqrt{-2700}$, or $81-30\sqrt{-3}$, will be $-3-2\sqrt{-3}$, $-\frac{1}{2}+\frac{1}{2}\sqrt{-3}$, and $\frac{9}{2}-\frac{1}{2}\sqrt{-3}$. And therefore $\sqrt[3]{81+\sqrt{-2700}}+\sqrt[3]{81-\sqrt{-2700}}$ $=-3\times 2=-6$, or $=-\frac{1}{2}\times 2=-3$, or $=\frac{9}{2}\times 2=9$, the imaginary parts vanishing by the contrariety of their signs.

We may obſerve likewiſe, that ſuch roots, whether expreſſible in rational numbers, or not, may be found by evolving the binomial $A+B\sqrt{-q}$ by the *Theorem* in *pag.* 41, and ſumming the alternate terms. As, in the foregoing example, $\overline{81+30\sqrt{-3}}^{\frac{1}{3}}$, or rather $\overline{81}^{\frac{1}{3}}\times\overline{1+\frac{10}{27}\sqrt{-3}}^{\frac{1}{3}}$, being expanded into a ſeries, the ſum of the odd terms will continually approach to 4. $5=\frac{9}{2}$, and the ſum of the coefficients of the even terms to $\frac{1}{2}$, which is the coefficient of the imaginary part. But for a general and elegant ſolution, recourſe muſt be had to Mr. *de Moivre*'s Appendix to Dr. *Saunderſon*'s Algebra, and the continuation of it in *Philoſ. Tranſ.* N° 451. What has been explained above may ſerve, for the preſent, to give the Learner ſome notion of the compoſition and reſolution of thoſe cubes; that he need not hereafter be ſurpriſed to meet with expreſſions of real quantities which involve imaginary roots.

*End of the* FIRST PART.



to the end of this Chapter.



parts changed." Thus the cube ro
$-2700$, or $81-30\sqrt{-3}$, will b
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re $\sqrt[3]{81+\sqrt{-2700}}+\sqrt[3]{81-\sqrt{-270}}$
$-6$, or $=-\frac{1}{2}\times 2=-3$, or $=\frac{1}{2}\times 2$
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A

# TREATISE OF ALGEBRA.

## PART II.

### Of the Geneſis and Reſolution of EQUATIONS of all degrees; and of the different Affections of the ROOTS.

### CHAP. I.

#### Of the Geneſis and Reſolution of Equations in general; and the number of roots an equation of any degree may have.

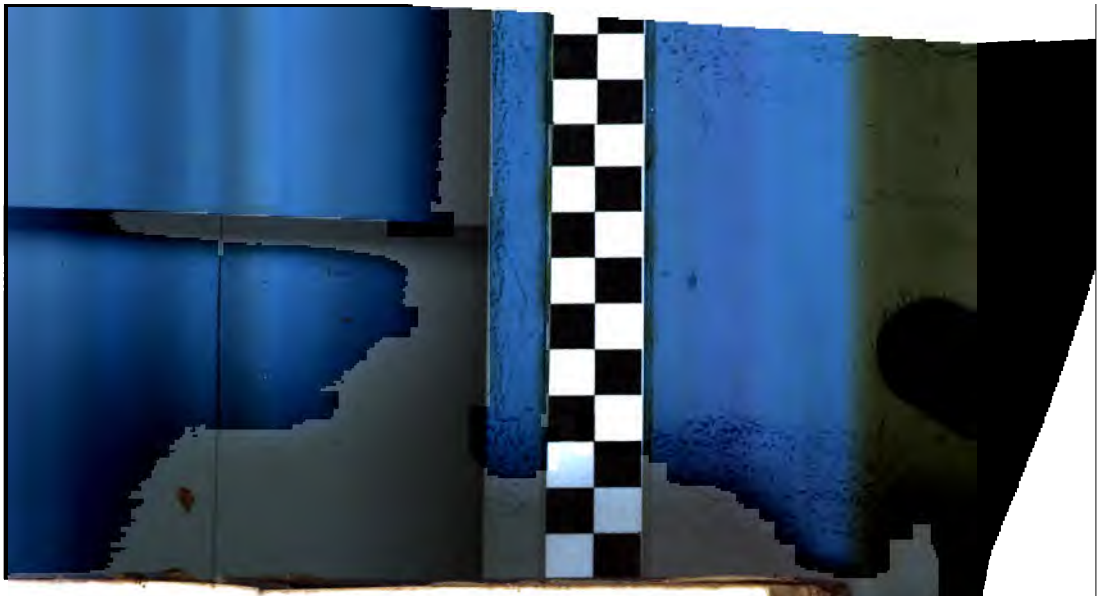
§ 1. AFTER the ſame manner as the higher powers are produced by the multiplication of the lower powers of the ſame root; equations of ſuperior orders are generated by the multiplication of equations of inferior orders involving the ſame unknown quantity. And *an equation of*

*any dimenſions may be conſidered as produced by the multiplication of as many ſimple equations as it has dimenſions*; or *of any other equations whatſoever, if the ſum of their dimenſions is equal to the dimenſion of that equation.* Thus any *cubic* equation may be conceived as generated by the multiplication of *three* ſimple equations, or of *one quadratic* and *one ſimple* equation. A *biquadratic* as generated by the multiplication of *four ſimple* equations, or of *two quadratic* equations; or laſtly, of *one cubic* and *one ſimple* equation.

§ 2. If the equations which you ſuppoſe multiplied by one another are *the ſame*, then the equation generated will be nothing elſe but ſome power of thoſe equations, and the operation is merely *involution*; of which we have treated already: and, when any ſuch equation is given, the ſimple equation by whoſe multiplication it is produced is found by *evolution*, or the extraction of a root.

But when the equations that are ſuppoſed to be multiplied by each other are *different*, then other equations than powers are generated; which to reſolve into the ſimple equations whence they are generated, is a different operation from involution, and is what is called, *The reſolution of equations.*

But as evolution is performed by obſerving and tracing back the ſteps of involution; ſo to diſcover





*ions may be considered as produced by t*
*ion of as many simple equations as t*
*ions; or of any other equations whos*
*the sum of their dimensions is equal*
*n of that equation.* Thus any cu
may be conceived as generated by
ication of *three* simple equations, o
*dratic* and *one simple* equation.
as generated by the multiplicatio
*ple* equations, or of *two quadrat*
or lastly, of *one cubic* and *one simp*

equations which you suppose mul
e another are *the same*, then th
rated will be nothing else but som
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*ion*; of which we have treated
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is what is called, *The resolution*

tion is performed by observing
the steps of involution; so to
discover





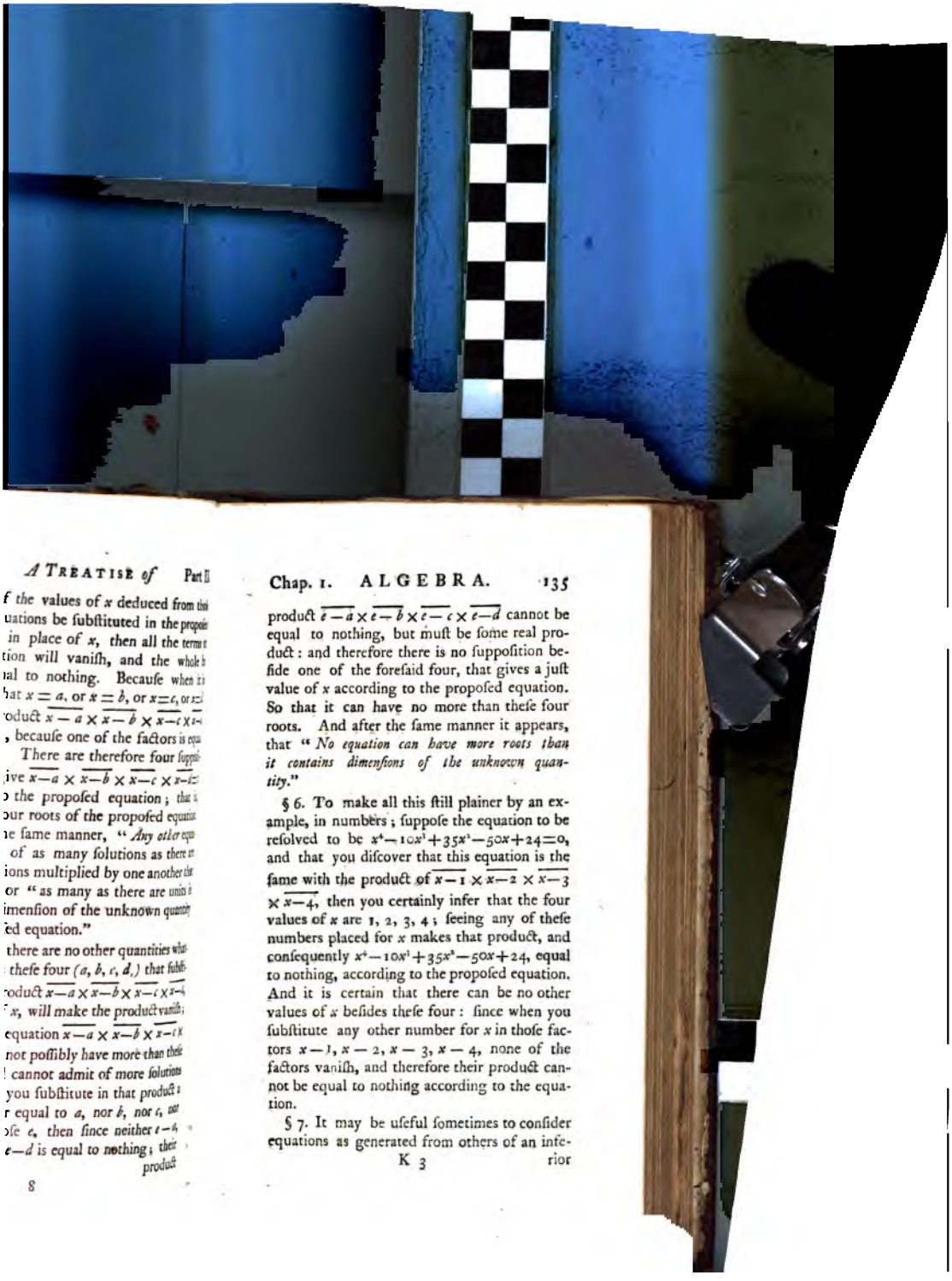
discover the rules for the resolution of equations, we must carefully observe their *generation.*

§ 3. Suppose the unknown quantity to be $x$ and its values in any simple equations to be $a$, $b$, $c$, $d$, &c. then those simple equations, by bringing all the terms to one side, become $x-a=0$, $x-b=0$, $x-c=0$, &c. And, the product of any two of these, as $\overline{x-a}\times\overline{x-b}=0$ will give a *quadratic* equation, or an equation of two dimensions. The product of any three of them, as $\overline{x-a}\times\overline{x-b}\times\overline{x-c}=0$ will give a *cubic* equation, or one of three dimensions. The product of any four of them will give a *biquadratic* equation, or one of four dimensions, as $\overline{x-a}\times\overline{x-b}\times\overline{x-c}\times\overline{x-d}=0$. And, *in general*, "*In the equation produced, the highest dimension of the unknown quantity will be equal to the number of simple equations that are multiplied by each other.*

§ 4. When any equation equivalent to this biquadratic $\overline{x-a}\times\overline{x-b}\times\overline{x-c}\times\overline{x-d}=0$ is proposed to be resolved, the whole difficulty consists in finding the simple equations $\overline{x-a}=0$, $\overline{x-b}=0$, $\overline{x-c}=0$, $\overline{x-d}=0$, by whose multiplication it is produced; for each of these simple equations gives one of the values of $x$, and one solution of the proposed equation. For,

if any of the values of $x$ deduced from thoſe ſimple equations be ſubſtituted in the propoſed equation, in place of $x$, then all the terms of that equation will vaniſh, and the whole be found equal to nothing. Becauſe when it is ſuppoſed that $x = a$, or $x = b$, or $x = c$, or $x = d$, then the product $\overline{x-a} \times \overline{x-b} \times \overline{x-c} \times \overline{x-d}$ does vaniſh, becauſe one of the factors is equal to nothing. There are therefore four ſuppoſitions that give $\overline{x-a} \times \overline{x-b} \times \overline{x-c} \times \overline{x-d} = 0$ according to the propoſed equation; that is, there are four roots of the propoſed equation. And after the ſame manner, "*Any other* equation admits of as many ſolutions as there are ſimple equations multiplied by one another that produce it," or "as many as there are units in the higheſt dimenſion of the unknown quantity in the propoſed equation."

§ 5. But as there are no other quantities whatſoever beſides theſe four $(a, b, c, d,)$ that ſubſtituted in the product $\overline{x-a} \times \overline{x-b} \times \overline{x-c} \times \overline{x-d}$, in the place of $x$, will make the product vaniſh; therefore, the equation $\overline{x-a} \times \overline{x-b} \times \overline{x-c} \times \overline{x-d} = 0$, cannot poſſibly have more than theſe four roots, and cannot admit of more ſolutions than four. If you ſubſtitute in that product a quantity neither equal to $a$, nor $b$, nor $c$, nor $d$, which ſuppoſe $e$, then ſince neither $e-a$, $e-b$, $e-c$, nor $e-d$ is equal to nothing; their product





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product $\overline{e-a} \times \overline{e-b} \times \overline{e-c} \times \overline{e-d}$ cannot be equal to nothing, but muſt be ſome real product: and therefore there is no ſuppoſition beſide one of the foreſaid four, that gives a juſt value of *x* according to the propoſed equation. So that it can have no more than theſe four roots. And after the ſame manner it appears, that "*No equation can have more roots than it contains dimenſions of the unknown quantity.*"

§ 6. To make all this ſtill plainer by an example, in numbers; ſuppoſe the equation to be reſolved to be $x^4 - 10x^3 + 35x^2 - 50x + 24 = 0$, and that you diſcover that this equation is the ſame with the product of $\overline{x-1} \times \overline{x-2} \times \overline{x-3} \times \overline{x-4}$, then you certainly infer that the four values of *x* are 1, 2, 3, 4; ſeeing any of theſe numbers placed for *x* makes that product, and conſequently $x^4 - 10x^3 + 35x^2 - 50x + 24$, equal to nothing, according to the propoſed equation. And it is certain that there can be no other values of *x* beſides theſe four: ſince when you ſubſtitute any other number for *x* in thoſe factors $x - 1$, $x - 2$, $x - 3$, $x - 4$, none of the factors vaniſh, and therefore their product cannot be equal to nothing according to the equation.

§ 7. It may be uſeful ſometimes to conſider equations as generated from others of an infe-

rior ſort beſides ſimple ones. Thus a *cubic* equation may be conceived as generated from the *quadratic* $x^2 - px + q = 0$, and the *ſimple* equation $x - a = 0$, multiplied by each other; whoſe product

$$\left.\begin{matrix} x^3 - px^2 + qx - aq \\ -ax^2 + apx \end{matrix}\right\} = 0$$ may expreſs any cubic equation whoſe roots are the quantity $(a)$ the value of $x$ in the ſimple equation, and the two roots of the quadratic equation, *viz.*

$\frac{p + \sqrt{p^2 - 4q}}{2}$ and $\frac{p - \sqrt{p^2 - 4q}}{2}$; as appears from *Chap.* 13. *Part* I. And, according as theſe roots are *real* or *impoſſible*, two of the roots of the cubic equation are *real* or *impoſſible*.

§ 8. In the doctrine of involution we ſhewed that "the ſquare of any quantity poſitive or negative, is always poſitive," and therefore "the ſquare root of a negative is impoſſible or imaginary." For example, the $\sqrt{a^2}$ is either $+a$ or $-a$; but $\sqrt{-a^2}$ can neither be $+a$ nor $-a$, but muſt be *imaginary*. Hence is underſtood that "a quadratic equation may have no impoſſible expreſſion in its coefficients, and yet, when it is reſolved into the ſimple equations that produce it, they may involve impoſſible expreſſions." Thus the quadratic equation $x^2 + a^2 = 0$ has no impoſſible coefficient, but the ſimple equations from which it is produced, *viz.* $x + \sqrt{-a^2} = 0$, and $x - \sqrt{-a^2} = 0$, both

both involve an imaginary quantity; as the ſquare $-a^2$ is a real quantity, but its ſquare root is imaginary. After the ſame manner a biquadratic equation, when reſolved, may give four ſimple equations, each of which may give an impoſſible value for the root: and the ſame may be ſaid of any equation that can be produced from quadratic equations only; that is, whoſe dimenſions are of the even numbers.

§ 9. But "a cubic equation (which cannot be generated from quadratic equations only, but requires one ſimple equation beſides to produce it) if none of its coefficients are impoſſible, will have, at leaſt, one real root," the ſame with the root of the ſimple equation whence it is produced. The ſquare of an impoſſible quantity may be real, as the ſquare of $\sqrt{-a^2}$ is $-a^2$; but "the cube of an impoſſible quantity is ſtill impoſſible," as it ſtill involves the ſquare root of a negative: as, $\sqrt[2]{-a^2} \times \sqrt[2]{-a^2} \times \sqrt[2]{-a^2} = \sqrt[2]{-a^6} = a^3\sqrt{-1}$, is plainly imaginary. From which it appears, that though two ſimple equations involving impoſſible expreſſions, multiplied by one another, may give a product where no impoſſible expreſſion may appear; yet "if three ſuch ſimple equations be multiplied by each other, the impoſſible expreſſion will not diſappear in their

product." And hence it is plain, that though a quadratic equation whose coefficients are all real may have its two roots impossible, yet "a cubic equation whose coefficients are real cannot have all its three roots impossible."

§ 10. In general, it appears that the impossible expressions cannot disappear in the equation produced, but when their number is *even*; that there are never in any equations, whose coefficients are real quantities, single impossible roots, or an odd number of impossible roots, but "that the roots become impossible in pairs;" and that "an equation of an odd number of dimensions has always one real root."

§ 11. The roots of equations are either *positive* or *negative* according as the roots of the simple equations whence they are produced are positive or negative." If you suppose $x = -a$, $x = -b$, $x = -c$, $x = -d$, &c. then shall $x+a=0$, $x+b=0$, $x+c=0$, $x+d=0$; and the equation $\overline{x+a} \times \overline{x+b} \times \overline{x+c} \times \overline{x+d} = 0$ will have its roots, $-a$, $-b$, $-c$, $-d$, &c. negative.

But to know when the roots of equations are positive and when negative, and how many there are of each kind, shall be explained in the next chapter.



CHAP.

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## CHAP. II.

### Of the Signs and Coefficients of EQUATIONS.

§ 12. WHEN any number of simple equations are multiplied by each other, it is obvious that the higheſt dimenſion of the unknown quantity in their product is equal to the number of thoſe ſimple equations; and, the term involving the higheſt dimenſion is called the *firſt* term of the equation generated by this multiplication. The term involving the next dimenſion of the unknown quantity, leſs than the greateſt by unit, is called the *ſecond* term of the equation; the term involving the next dimenſion of the unknown quantity, which is leſs than the greateſt by two, the *third* term of the equation, &c. And that term which involves no dimenſion of the unknown quantity, but is ſome known quantity, is called the *laſt* term of the equation.

"*The number of terms is always greater than the higheſt dimenſion of the unknown quantity by unit.*" And when any term is wanting, an *aſteriſk* is marked in its place. The *ſigns* and *coefficients* of equations will be underſtood by conſidering the following TABLE, where the ſimple

ſimple equation $x-a$, $x-b$, &c. are multiplied by one another, and produce ſucceſſively the higher equations.

$$\begin{array}{l} x-a=0 \\ \times\ x-b=0 \\ \hline =x^2-ax-bx+ab=0, \text{ a Quadratic.} \\ \times\ x-c=0 \\ \hline =x^3-ax^2-bx^2-cx^2+abx+acx+bcx-abc=0, \text{ a Cubic.} \\ \times\ x-d=0 \\ \hline =x^4-ax^3-bx^3-cx^3-dx^3+abx^2+acx^2+adx^2+bcx^2+bdx^2+cdx^2-abcx-abdx-acdx-bcdx+abcdx=0, \text{ a Biquadratic.} \\ \times\ x-e=0 \\ \hline =x^5-ax^4-bx^4-cx^4-dx^4-ex^4+abx^3+acx^3+adx^3+aex^3+bcx^3+bdx^3+bex^3+cdx^3+cex^3+dex^3-abcx^2-abdx^2-abex^2-acdx^2-adex^2-acex^2-bcdx^2-bcex^2-bdex^2-cdex^2+abcdx^2+abcex^2+abdex^2+acdex^2+bcdex-abcdex=0, \text{ a Surſolid.} \\ \&c. \end{array}$$

§ 13.

uation $x - a$, $x - b$, &c. are mul
ne another, and produce succeſſive
equations.

$\}$ =0, a Quadratic.

$+ab$
$+ac$ $\}$ $\times x - abc = 0$, a Cubic.
$+bc$

$+ab$ $-abc$
$+ac$ $-abd$
$+ad$ $-aed$ $\times x + abcd = 0$, a Bi
$+bc$ $\times x^2$ $-bcd$ [quadratic.
$+bd$
$+cd$

$-abc$ $+abcd$
$-abd$ $+abce$ $x -$
$-abe$ $+abde$ $abcde = 0$,
$-acd$ $+acde$ a biſſe
$-ade$ $\times x^3$ $+bcde$ lid.
$-ace$
$-bcd$ $\times x^2$
$-bce$
$-bde$
$-cde$
&c.





§ 13. From the inſpection of theſe equations it is plain, that the coefficients of the firſt term is *unit*.

The coefficient of the ſecond term is *the ſum of all the roots (a, b, c, d, e) having their ſigns changed.*

The coefficient of the third term is *the ſum of all the products that can be made by multiplying any two of the roots (a, b, c, d, e) by one another.*

The coefficient of the fourth term is *the ſum of all the products that can be made by multiplying into one another any three of the roots, with their ſigns changed.* And after this [illegible] manner all the other coefficients are formed.

The laſt term is [illegible] *the product of all the roots having their ſigns changed*, multiplied by one another.

§ 14. Although in the Table ſuch ſimple equations only are multiplied by one another as have poſitive roots, it is eaſy to ſee, that "the coefficients will be formed according to the ſame rule when any of the ſimple equations have negative roots." And, *in general*, if $x^5 - px^4 + qx - r = 0$ repreſent any cubic equation, then ſhall $p$ be the ſum of the roots; $q$ the ſum of the products made by multiplying any two of them; $r$ the product of all the three: and, if $-p$, $+q$, $-r$, $+s$, $-t$, $+u$, &c. be the coefficients of the 2d, 3d, 4th, 5th, 6th, 7th, &c.

&c. terms of any equation, then ſhall $p$ be the ſum of all the roots, $q$ the ſum of the products of any two, $r$ the ſum of the products of any three, $s$ the ſum of the products of any four, $t$ the ſum of the products of any five, $u$ the ſum of the products of any ſix, &c.

§ 15. When therefore any equation is propoſed to be reſolved, it is eaſy to find the ſum of the roots, (for it is equal to the coefficient of the ſecond term having its ſign changed:) or, to find the ſum of the products that can be made by multiplying any determinate number of them.

But it is alſo eaſy "to find the ſum of the ſquares, or of any powers, of the roots."

The ſum of the ſquares is always $p^2 - 2q$. For calling the ſum of the ſquares $B$, ſince the ſum of the roots is $p$; and "the ſquare of the ſum of any quantities is always equal to the ſum of their ſquares added to double the products that can be made by multiplying any two of them," therefore $p^2 = B + 2q$, and conſequently $B = p^2 - 2q$. For example, $\overline{a+b+c}^2 = a^2 + b^2 + c^2 + 2ab + 2ac + 2bc$; that is, $p^2 = B + 2q$. And $\overline{a+b+c+d}^2 = a^2 + b^2 + c^2 + d^2 + 2 \times ab + ac + ad + bc + bd + cd$, that is again, $p^2 = B + 2q$, or $B = p^2 - 2q$. And ſo for any other number of quantities. In general therefore, "$B$ the ſum of the ſquares of the roots

ns of any equation, then ſhall p
of all the roots, q the ſum of
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For example, $\overline{a+b+c}^2 =$
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$\overline{a+b+c+d}^2 = a^2 + b^2 +$
$+ ac + ad + bc + bd + cd$, that
$+ 2q$, or $B = p^2 - 2q$. And
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the ſum of the ſquares of the
roots



roots may always be found by ſubtracting $2q$ from $p^2$;" the quantities $p$ and $q$ being always known, ſince they are the coefficients in the propoſed equation.

§ 16. "The ſum of the cubes of the roots of any equation is equal to $p^3 - 3pq + 3r$, or to $Bp - pq + 3r$." For $\overline{B-q} \times p$ gives always the exceſs of the ſum of the cubes of any quantities above the triple ſum of the products that can be made by multiplying any three of them. Thus $\overline{a^2+b^2+c^2-ab-ac-bc} \times \overline{a+b+c} (= \overline{B-q} \times p) = a^3 + b^3 + c^3 - 3abc$. Therefore if the ſum of the cubes is called $C$, then ſhall $\overline{B-q} \times p = C - 3r$, and $C = Bp - qp + 3r$ (becauſe $B = p^2 - 2q$) $= p^3 - 3pq + 3r$.

After the ſame manner, if $D$ be the ſum of the 4th powers of the roots, you will find that $D = pC - qB + pr - 4s$: and if $E$ be the ſum of the 5th powers then ſhall $E = pD - qC + rB - ps + 5t$. And after the ſame manner the ſum of any powers of the roots may be found; the progreſſion of theſe expreſſions of the ſum of the powers being obvious.

§ 17. As for the ſigns of the terms of the equation produced, it appears from inſpection that the ſigns of all the terms in any equation in the Table are alternately $+$ and $-$: theſe equations are generated by multiplying continually $x - a$, $x - b$, $x - c$, $x - d$, &c. by one another.

another. The firſt term is always ſome pure power of $x$, and is poſitive; the ſecond is a power of $x$ multiplied by the quantities $-a$, $-b$, $-c$, &c. And ſince theſe are all negative, that term muſt therefore be negative. The third term has the products of any two of theſe quantities ($-a$, $-b$, $-c$, &c.) for its coefficient; which products are all poſitive, becauſe $-\times-$ gives $+$. For the like reaſon, the next coefficient, conſiſting of all the products made by multiplying any three of theſe quantities, muſt be negative; and the next poſitive. So that the coefficients. in this caſe, will be poſitive and negative by turns. But "in this caſe the roots are all poſitive;" ſince $x=a$, $x=b$, $x=c$, $x=d$, $x=e$, &c. are the aſſumed ſimple equations. It is plain then, that "*when all the roots are poſitive, the ſigns are alternately* $+$ *and* $-$."

§ 18. But if the roots are all negative, then $\overline{x+a}\times\overline{x+b}\times\overline{x+c}\times\overline{x+d}$, &c. $=0$, will expreſs the equation to be produced; all whoſe terms will plainly be poſitive; ſo that "*when all the roots of an equation are negative, it is plain there will be no changes in the ſigns of the terms of that equation.*"

§ 19. In general, "there are as many poſitive roots in any equation as there are changes in the ſigns of the terms from $+$ to $-$, or from $-$ to $+$; and the remaining roots are negative."





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and the remaining roots are
negative."



negative." The Rule is general, if the impoſſible roots be allowed to be either poſitive or negative.

§ 20. In quadratic equations, the two roots are either both poſitive, as in this

$$(\overline{x-a} \times \overline{x-b} =)\ x^2 - ax + ab = 0,$$
$$\qquad\qquad -bx$$

where there are two changes of the ſigns: Or they are both negative, as in this

$$(\overline{x+a} \times \overline{x+b} =)\ x^2 \left\{ \begin{matrix} +a \\ +b \end{matrix} \right\} x + ab = 0.$$

where there is not any change of the ſigns. Or there is one poſitive and one negative, as in

$$(\overline{x-a} \times \overline{x+b} =)\ x^2 \left\{ \begin{matrix} -a \\ +b \end{matrix} \right\} x - ab = 0,$$

where there is neceſſarily one change of the ſigns; becauſe the firſt term is poſitive, and the laſt negative, and there can be but one change whether the ſecond term be + or —.

Therefore the rule given in the 19th ſection extends to all quadratic equations.

§ 21. In cubic equations, the roots may be,

1°. All poſitive as in this, $\overline{x-a} \times \overline{x-b} \times \overline{x-c} = 0$, in which the ſigns are alternately + and —, as appears from the Table; and there are three changes of the ſigns.

2°. The roots may be all negative, as in the equation $\overline{x+a} \times \overline{x+b} \times \overline{x+c} = 0$, where there can be no change of the ſigns. Or,

3°.

3°. There may be two positive roots and one negative, as in the equation $\overline{x-a} \times \overline{x-b} \times \overline{x+c} = 0$, which gives

$$\left.\begin{matrix} x^3-a \\ -b \\ +c \end{matrix}\right\} \left.\begin{matrix} +ab \\ x^2-ac \\ -bc \end{matrix}\right\} x + abc = 0.$$

Here there must be two changes of the signs: because if $a+b$ is greater than $c$, the second term must be negative, its coefficient being $-a$, $-b+c$.

And if $a+b$ is less than $c$, then the third term must be negative, its coefficient $+ab - ac - bc$ $(ab - c \times \overline{a+b})$ * being in that case negative. And there cannot possibly be three changes of the signs, the first and last terms having the same sign.

4°. There may be one positive root and two negative, as in the equation $\overline{x+a} \times \overline{x+b} \times \overline{x-c} = 0$, which gives

$$\left.\begin{matrix} x^3+a \\ +b \\ -c \end{matrix}\right\} \left.\begin{matrix} +ab \\ x^2-ac \\ -bc \end{matrix}\right\} x - abc = 0.$$

Where there must be always one change of the signs, since the first term is positive and the last negative. And there can be but one change of the signs, since if the second term is negative, or $a+b$ less than $c$, the third must be

*Because the rectangle $a \times b$ is less than the square $\overline{a+b} \times \overline{a+b}$, and therefore much less than $\overline{a+b} \times c$.

negative





ere may be two positive roots a
ive, as in the equation $\overline{x-a} \times \overline{x-}$
$= 0$, which gives

$$\left.\begin{matrix} a \\ b \end{matrix}\right\} \left.\begin{matrix} +ab \\ x^3 - ac \\ -bc \end{matrix}\right\} x + abc = 0.$$

muſt be two changes of the ſigns
$+ b$ is greater than $c$, the ſecon
e negative, its coefficient being $-$

$+ b$ is leſs than $c$, then the thi
negative, its coefficient $+a$
$- c \times \overline{a + b}$) * being in that ca
nd there cannot poſſibly be thre
he ſigns, the firſt and laſt term
ne ſign.
nay be one poſitive root and tw
n the equation $\overline{x + a} \times \overline{x+}$

iich gives

$$\left.\begin{matrix} +ab \\ x^3 - ac \\ -bc \end{matrix}\right\} x - abc = 0.$$

uſt be always one change of the
firſt term is poſitive and the
nd there can be but one chang
ıce if the ſecond term is ne-
leſs than $c$, the third muſt be

ıngle $a \times b$ is leſs than the ſquare
therefore much leſs than $\overline{a+b} \times c$.
negative



negative alſo, ſo that there will be but one change of the ſigns. Or, if the ſecond term is affirmative, whatever the third term is, there will be but one change of the ſigns. It appears therefore, in general, that in cubic equations, there are as many affirmative roots as there are changes of the ſigns of the terms of the equation.

The ſame way of reaſoning may be extended to equations of higher dimenſions, and the rule delivered in § 19, extended to all kinds of equations.

§ 22. There are ſeveral conſectaries of what has been already demonſtrated, that are of uſe in diſcovering the roots of equations. But before we proceed to that, it will be convenient to explain ſome transformations of equations, by which they may often be rendered more ſimple, and the inveſtigation of their roots more eaſy.

## CHAP. III.

### Of the Transformation of EQUATIONS; and exterminating their intermediate terms.

§ 23. WE now proceed to explain the transformations of equations that are moſt uſeful: and firſt, "*The affirmative roots of an equation are changed into negative roots of the ſame value, and the negative roots into affirmative, by only changing the ſigns of the terms alternately, beginning with the ſecond.*" Thus the roots of the equation $x^4 - x^3 - 19x^2 + 49x - 30 = 0$ are $+1, +2, +3, -5$; whereas the roots of the ſame equation having only the ſigns of the ſecond and fourth terms changed, *viz.* $x^4 + x^3 - 19x^2 - 49x - 30 = 0$, are $-1, -2, -3, +5$.

To underſtand the reaſon of this rule, let us aſſume an equation, as $\overline{x-a} \times \overline{x-b} \times \overline{x-c} \times \overline{x-d} \times \overline{x-e}$, &c. $= 0$, whoſe roots are $+a, +b, +c, +d, +e$, &c. and another having its roots of the ſame value, but affected with contrary ſigns, as $\overline{x+a} \times \overline{x+b} \times \overline{x+c} \times \overline{x+d} \times \overline{x+e}$, &c. $= 0$. It is plain, that the terms taken alternately, beginning from the firſt, are the ſame

in





## CHAP. III.

### Transformation of Equa- ; and exterminating the ediate terms.

E now proceed to explain s transformations of equations the ful: and first, "*The affirmati quation are changed into negati ame value, and the negative ro e, by only changing the signs of th ely, beginning with the firſt* s of the equation $x^4 - x^3 - 19$ are $+1, +2, +3, -5$; where f the ſame equation having only ſecond and fourth terms changed, $19x^2 - 49x - 30 = 0$, are $-$,

nd the reaſon of this rule, let us ion, as $\overline{x-a} \times \overline{x-b} \times \overline{x-c} \times$ &c. $= 0$, whoſe roots are $+a$ $+e$, &c. and another having its value, but affected with contra- $\times \overline{x+b} \times \overline{x+c} \times \overline{x+d} \times \overline{x+e}$ plain, that the terms taken al- ing from the firſt, are the ſame in



in both equations, and have the ſame ſign, "being products of an even number of the roots;" the product of any two roots having the ſame ſign as their product when both their ſigns are changed; as $+a \times -b = -a \times +b$.

But the ſecond terms and all taken alternately from them, becauſe their coefficients involve always the products of an odd number of the roots, will have contrary ſigns in the two equations. For example, the product of four, *viz. abcd*, having the ſame ſign in both, and one equation in the fifth term having $abcd \times +e$, and the other $abcd \times -e$, it follows that their product *abcde* muſt have contrary ſigns in the two equations: theſe two equations therefore that have the ſame roots, but with contrary ſigns, have nothing different but the ſigns of the alternate terms, beginning with the ſecond. From which it follows, "that if any equation is given, and you change the ſigns of the alternate terms, beginning with the ſecond, the new equation will have roots of the ſame value, but with contrary ſigns."

§ 24. It is often very uſeful "*to transform an equation into another that ſhall have its roots greater or leſs than the roots of the propoſed equation by ſome given difference.*"

Let the equation propoſed be the cubic $x^3 - px^2 + qx - r = 0$. And let it be required to transform it into another equation whoſe roots

ſhall be leſs than the roots of this equation by ſome given difference $(e)$, that is, ſuppoſe $y = x - e$, and conſequently $x = y + e$; then inſtead of $x$ and its powers, ſubſtitute $y + e$ and its powers, and there will ariſe this new equation,

$$(A)\ \left.\begin{array}{r} y^3 + 3ey^2 + 3e^2y + e^3 \\ - py^2 - 2pey - pe^2 \\ + qy + qe \\ - r \end{array}\right\} = 0.$$

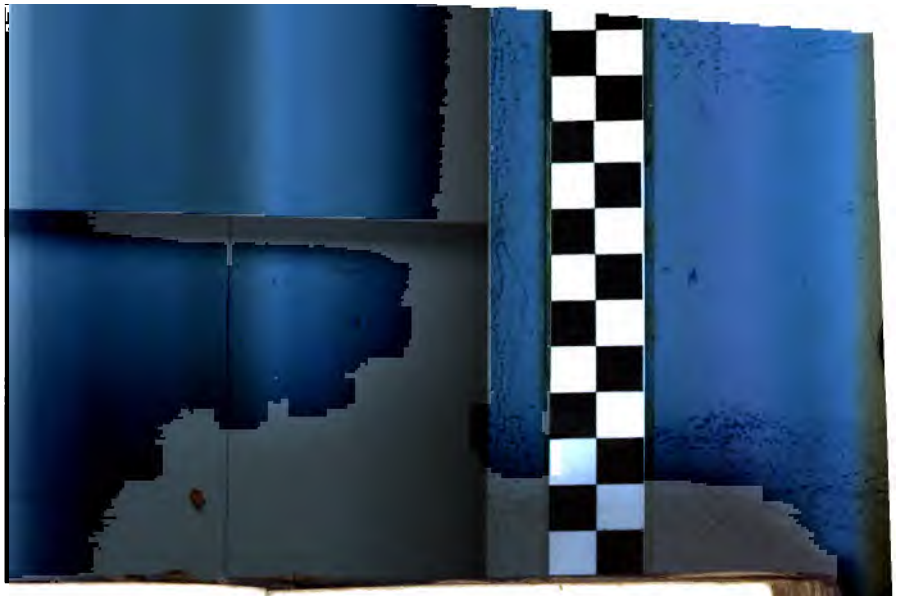
whoſe roots are leſs than the roots of the preceding equation by the difference $(e)$.

If it had been required to find an equation whoſe roots ſhould be greater than thoſe of the propoſed equation by the quantity $(e)$, then we muſt have ſuppoſed $y = x + e$, and conſequently $x = y - e$, and then the other equation would have had this form;

$$(B)\ \left.\begin{array}{r} y^3 - 3ey^2 + 3e^2y - e^3 \\ - py^2 + 2pey - pe^2 \\ + qy - qe \\ - r \end{array}\right\} = 0.$$

If the propoſed equation be in this form, $x^3 + px^2 + qx + r = 0$, then by ſuppoſing $x + e = y$ there will ariſe an equation agreeing in all reſpects with the equation $(A)$, but that the ſecond and fourth terms will have contrary ſigns.

And





ess than the roots of this equation b
en difference (e), that is, suppos
and consequently $x = y + e$; the
$x$ and its powers, substitute $y+$
wers, and there will arise this ne

$$\left.\begin{array}{rrrr} + 3ey^2 & + 3e^2y & + e^3 \\ - py^2 & - 2pey & - pe^2 \\ + qy & + qe & \\ - r & & \end{array}\right\} = 0.$$

are less than the roots of the pr
ion by the difference (e).

been required to find an equation
should be greater than those o
equation by the quantity (e), then
supposed $y = x + e$, and conse
$- e$, and then the other equation
ad this form;

$$\left.\begin{array}{rrrr} \cdot ey^2 & + 3e^2y & - e^3 \\ y^2 & + 2pey & - pe^2 \\ + qy & - qe & \\ & - r & \end{array}\right\} = 0.$$

sed equation be in this form,
$= 0$, then by supposing $x + (=)$
an equation agreeing in all re-
quation (A), but that the se-
terms will have contrary signs.

And



And by supposing $x - e = y$, there will arise an equation agreeing with (B) in all respects, but that the second and fourth terms will have contrary signs to what they have in (B).

The first of these suppositions gives this equation,

$$(C)\ \left.\begin{array}{rrrr} y^3 - 3ey^2 & + 3e^2y & - e^3 \\ + py^2 & - 2pey & + pe^2 \\ + qy & - qe & \\ & + r & \end{array}\right\} = 0.$$

The second supposition gives the equation

$$(D)\ \left.\begin{array}{rrrr} y^3 + 3ey^2 & + 3e^2y & + e^3 \\ + py^2 & + 2epy & + pe^2 \\ + qy & + qe & \\ & + r & \end{array}\right\} = 0.$$

§ 25. The first use of this transformation of equations is to shew "*how the second (or other intermediate) term may be taken away out of an equation.*"

It is plain that in the equation (A) whose second term is $\overline{3e - p} \times y^2$, if you suppose $e = \frac{1}{3}p$, and consequently $3e - p = 0$, then the second term will vanish.

In the equation (C) whose second term is $-\overline{3e + p} \times y^2$, supposing $e = \frac{1}{3}p$, the second term also vanishes.

Now the equation (A) was deduced from $x^3 - px^2 + qx - r = 0$, by supposing $y = x - e$:

and the equation (*C*) was deduced from $x^3 + px^2 + qx + r = 0$; by ſuppoſing $y = x + e$. From which this Rule may eaſily be deduced for exterminating the ſecond term out of any cubic equation.

## RULE.

"*Add to the unknown quantity of the given equation the third part of the coefficient of the ſecond term with its proper ſign*, viz. $\mp \frac{1}{3}p$, *and ſuppoſe this aggregate equal to a new unknown quantity* ($y$). *From this value of* $y$ *find a value of* $x$ *by tranſpoſition, and ſubſtitute this value of* $x$ *and its powers in the given equation, and there will ariſe a new equation that ſhall want the ſecond term.*"

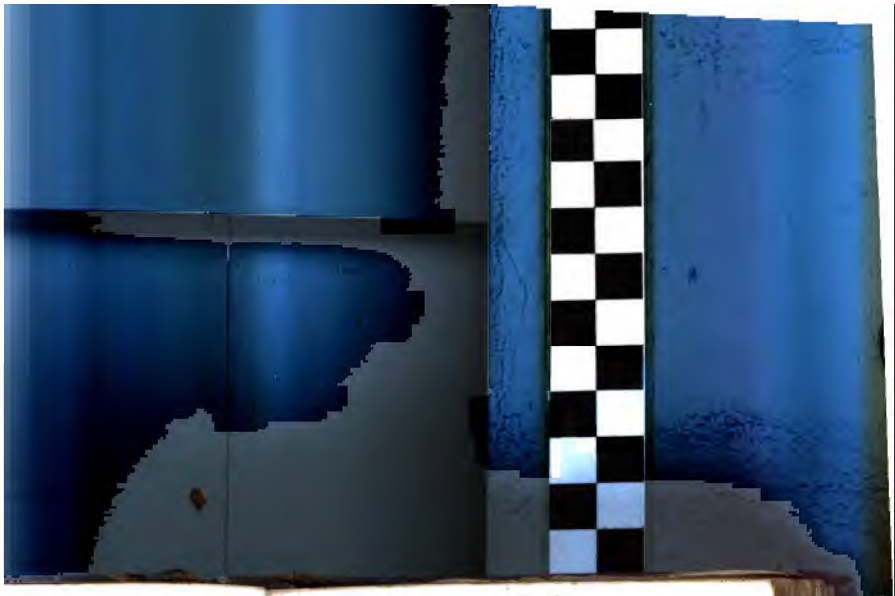
## EXAMPLE.

Let it be required to exterminate the ſecond term out of this equation, $x^3 - 9x^2 + 26x - 34 = 0$, ſuppoſe $x - 3 = y$, or $y + 3 = x$; and ſubſtituting according to the Rule, you will find

$$\left.\begin{array}{r} y^3 + 9y^2 + 27y + 27 \\ -9y^2 - 54y - 81 \\ +26y + 78 \\ -34 \end{array}\right\} = 0$$

$$y^3 \quad * \quad -y \quad -10 = 0.$$

In





uation (C) was deduced from $x^3+px$
$=0$; by ſuppoſing $y=x+e$. From
Rule may eaſily be deduced for ex
the ſecond term out of any cubic

## RULE.

*unknown quantity of the given equa*
*third part of the coefficient of th*
*with its proper ſign*, viz. $\mp\frac{1}{3}p$
*this aggregate equal to a new un*
*tity* ($y$). *From this value of $y$ fin*
*by tranſpoſition, and ſubſtitute thi*
*and its powers in the given equa*
*here will ariſe a new equation tha*
*be ſecond term.*"

## EXAMPLE.

quired to exterminate the ſecond
is equation, $x^3-9x^2+26x-$
e $x-3=y$, or $y+3=x$; and
ording to the Rule, you will find

$$\left.\begin{array}{r} +27y+27 \\ -54y-81 \\ +26y+78 \\ \hline -34 \end{array}\right\}=0$$

$$-y-10=0.$$

In



In which there is no term where $y$ is of two dimenſions, and an aſteriſk is placed in the room of the ſecond term, to ſhew it is wanting.

§ 26. Let the equation propoſed be of any number of dimenſions repreſented by $(n)$; and let the coefficient of the ſecond term with its ſign prefixed be $-p$, then ſuppoſing $x-\frac{p}{n}=y$, and conſequently $x=y+\frac{p}{n}$, and ſubſtituting this value for $x$ in the given equation, there will ariſe a new equation that ſhall want the ſecond term.

It is plain from what was demonſtrated in *Chap.* 2. that the ſum of the roots of the propoſed equation is $+p$; and ſince we ſuppoſe $y=x-\frac{p}{n}$, it follows, that in the new equation, each value of $y$ will be leſs than the reſpective value of $x$ by $\frac{p}{n}$; and, ſince the number of the roots is $n$, it follows that the ſum of the values of $y$ will be leſs than $+p$, the ſum of the values of $x$, by $n\times\frac{p}{n}$ the difference of any two roots, that is, by $+p$: therefore the ſum of the values of $y$ will be $+p-p=0$.

But the coefficient of the ſecond term of the equation of $y$ is the ſum of the values of $y$, viz. $+p-p$, and therefore that coefficient is equal to nothing; and conſequently, in the equation

of $y$, the ſecond term vaniſhes. It follows then, that the ſecond term may be exterminated out of any given equation by the following

RULE.

"*Divide the coefficient of the ſecond term of the propoſed equation by the number of dimenſions of the equation; and aſſuming a new unknown quantity $y$, add to it the quotient having its ſign changed. Then ſuppoſe this aggregate equal to $x$ the unknown quantity in the propoſed equation; and for $x$ and its powers, ſubſtitute the aggregate and its powers, ſo ſhall the new equation that ariſes want its ſecond term.*"

§ 27. If the propoſed equation is a quadratic, as $x^2 - px + q = 0$, then, according to the rule, ſuppoſe $y + \frac{1}{2}p = x$, and ſubſtituting this value for $x$, you will find,

$$\left.\begin{array}{r} y^2 + py + \frac{1}{4}p^2 \\ -py - \frac{1}{2}p^2 \\ + q \end{array}\right\} = 0$$

$$y^2 \quad * \quad - \frac{1}{4}p^2 + q = 0.$$

And from this example the uſe of exterminating the ſecond term appears: for commonly the ſolution of the equation that wants the ſecond term is more eaſy. And, if you can find the value

econd term vaniſhes. It follows that
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n equation by the following

RULE.

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*ation; and aſſuming a new unknown*
*add to it the quotient having it*
*ed. Then ſuppoſe this aggregate*
*the unknown quantity in its ſe*
*ion; and for x and its powers*
*be aggregate and its powers,*
*e equation that ariſes want its ſe*

propoſed equation is a quadratic,
$q = 0$, then, according to the
$+ \frac{1}{2}p = x$, and ſubſtituting this
u will find,

$$\left.\begin{matrix} \cdot\ py + \frac{1}{4}p^2 \\ py - \frac{1}{4}p^2 \\ + \quad q \end{matrix}\right\} = 0$$

$$* \quad - \frac{1}{4}p^2 + q = 0.$$

ample the uſe of exterminat-
m appears: for commonly the
uation that wants the ſecond
ſy. And, if you can find the
value



value of $y$ from this new equation, it is eaſy to find the value of $x$ by means of the equation $y + \frac{1}{2}p = x$. For example,

Since $y^2 + q - \frac{1}{4}p^2 = 0$, it follows that

$$y^2 = \frac{1}{4}p^2 - q, \text{ and } y = \pm\sqrt{\tfrac{1}{4}p^2 - q}, \text{ ſo}$$

that $x = y + \frac{1}{2}p = \frac{1}{2}p \pm \sqrt{\frac{1}{4}p^2 - q}$;

which agrees with what we demonſtrated, *Chapter* 13. *Part.* I.

If the propoſed equation is a biquadratic, as $x^4 - px^3 + qx^2 - rx + s = 0$, then by ſuppoſing $x - \frac{1}{2}p = y$, or $x = y + \frac{1}{2}p$, an equation ſhall ariſe having no ſecond term. And if the propoſed is of five dimenſions, then you muſt ſuppoſe $x = y \pm \frac{1}{2}p$. And ſo on.

§ 28. When the ſecond term in any equation is wanting, it follows, that, "the equation has both affirmative and negative roots," and that the ſum of the affirmative roots is equal to the ſum of the negative roots: by which means the coefficient of the ſecond term, which is the ſum of all the roots of both ſorts, vaniſhes, and makes the ſecond term vaniſh.

*In general*, "the coefficient of the ſecond term is the difference between the ſum of the affirmative roots and the ſum of the negative roots:" and the operations we have given ſerve only to diminiſh all the roots when the ſum of the affirmative is greateſt, or increaſe the roots when the ſum of the negative is greateſt, ſo

as

as to balance them, and reduce them to an equality.

It is obvious, that in a quadratic equation that wants the second term, there must be one root affirmative and one negative; and these must be equal to one another.

In a cubic equation that wants the second term, there must be either, two affirmative roots equal, taken together, to a third root that must be negative; or, two negative equal to a third that must be positive.

"Let an equation $x^3 - px^2 + qx - r = 0$ be proposed, and let it be now required to exterminate the third term."

By supposing $y = x - e$, the coefficient of the third term in the equation of $y$ is found (see equation *A*) to be $3e^2 - 2pe + q$. Suppose that coefficient equal to nothing, and by resolving the quadratic equation $3e^2 - 2pe + q = 0$, you will find the value of $e$, which substituted for it in the equation $y = x - e$, will shew how to transform the proposed equation into one that shall want the third term.

The quadratic $3e^2 - 2pe + q = 0$ gives $e = \frac{p \pm \sqrt{p^2 - 3q}}{3}$. So that the proposed cubic will be transformed into an equation wanting the third term by supposing $y = x - \frac{p - \sqrt{p^2 - 3q}}{3}$, or $y = x - \frac{p + \sqrt{p^2 - 3q}}{3}$.

If

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$y = x - e$, the coefficient of the
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So that the proposed cubic
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ppoſing $y = x - \frac{p - \sqrt{p^2 - 3q}}{3}$,
$= 3q$.

If



If the proposed equation is of $n$ dimensions, the value of $e$, by which the third term may be taken away, is had by resolving the quadratic equation $e^2 + \frac{2p}{n} \times e + \frac{2q}{n \times n-1} = 0$, supposing $-p$ and $+q$ to be the coefficients of the second and third terms of the proposed equation.

The fourth term of any equation may be taken away by solving a cubic equation, which is the coefficient of the fourth term in the equation when transformed, as in the second article of this chapter. The fifth term may be taken away by solving a biquadratic; and after the same manner the other terms can be exterminated if there are any.

§ 29. There are other tranſmutations of equations, that on ſome occaſions are uſeful.

An equation, as $x^3 - px^2 + qx - r = 0$, *may be transformed into another that ſhall have its roots equal to the roots of this equation multiplied by a given quantity*, as $f$, by ſuppoſing $y = fx$, and conſequently $x = \frac{y}{f}$, and ſubſtituting this value for $x$ in the propoſed equation, there will ariſe $\frac{y^3}{f^3} - \frac{py^2}{f^2} + \frac{qy}{f} - r = 0$, and multiplying all by $f^3 \ldots y^3 - fpy^2 + f^2qy - f^3r = 0$, where the coefficient of the ſecond term of the propoſed equation multiplied into $f$ makes the coefficient of the

the ſecond term of the transformed equation; and the following coefficients are produced by the following coefficients of the propoſed equation (as $q$, $r$, &c.) multiplied into the powers of $f$ ($f^2$, $f^3$, &c.)

Therefore "to transform any equation into another whoſe roots ſhall be equal to the roots of the propoſed equation multiplied by a given quantity" *(f)*, you need only multiply the terms of the propoſed equation, beginning at the ſecond term, by $f$, $f^2$, $f^3$, $f^4$, &c. and putting $y$ inſtead of $x$ there will ariſe an equation having its roots equal to the roots of the propoſed equation multiplied by *(f)* as required.

§ 30. The transformation mentioned in the laſt article is of uſe when the higheſt term of the equation has a coefficient different from unity; for, by it, the equation may be transformed into one that ſhall have the coefficient of the higheſt term unit.

If the equation propoſed is $ax^3 - px^2 + qx - r = 0$, then transform the equation into one whoſe roots are equal to the roots of the propoſed equation multiplied by *(a)*. That is, ſuppoſe $y = ax$, or $x = \frac{y}{a}$, and there will ariſe $\frac{ay^3}{a^3} - \frac{py^2}{a^2} + \frac{qy}{a} - r = 0$; ſo that $y^3 - py^2 + qay - ra^3 = 0$.

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multiplied by $(a)$. That is,

or $x=\frac{y}{a}$, and there will ariſe

$-r=0$; ſo that $y^3-py^2+$

From

From which we eaſily draw this

RULE.

"*Change the unknown quantity $x$ into another $y$, prefix no coefficient to the higheſt term, paſs the ſecond, multiply the following terms, beginning with the third, by $a$, $a^2$, $a^3$, $a^4$, &c. the powers of the coefficient of the higheſt term of the propoſed equation, reſpectively.*"

Thus the equation $3x^3-13x^2+14x+16=0$, is transformed into the equation
$y^3-13y^2+14\times 3\times x+16\times 9=0$, or
$y^3-13y^2+42x+144=0$.

Then finding the roots of this equation, it will eaſily be diſcovered what are the roots of the propoſed equation: ſince $3x=y$, or $x=\frac{1}{3}y$. And therefore ſince one of the values of $y$ is $-2$, it follows that one of the values of $x$ is $-\frac{2}{3}$.

§ 31. By the laſt Rule "*an equation is eaſily cleared of fractions.*" Suppoſe the equation propoſed is $x^3-\frac{p}{m}x^2+\frac{q}{n}x-\frac{r}{e}=0$. Multiply all the terms by the product of the denominators, you find
$mne\times x^3-nep\times x^2+meq\times x-mnr=0$.
Then (by laſt ſection) transforming the equation into one that ſhall have unit for the coefficient of the higheſt term, you find
$y^3-nep\times y^2+m^1n^1e^2nq\times y-m^3n^3e^3r=0$.

Or,

Or, neglecting the denominator of the laſt term $\frac{r}{e}$, you need only multiply all the equation by $mn$, which will give

$mn \times x^3 - np \times x^2 + mq \times x - \frac{mnr}{e} = 0$. And then $y^3 - np \times y^2 + m^2nq \times y - \frac{m^3n^3r}{e} = 0$.

Now after the values of $y$ are found, it will be eaſy to diſcover the values of $x$; ſince, in the firſt caſe, $x = \frac{y}{mne}$; in the ſecond, $x = \frac{y}{mn}$.

For example, the equation

$x^{18} - \frac{4}{3}x - \frac{146}{27} = 0$, is firſt reduced to this form $3x^{18} - 4x - \frac{146}{9} = 0$, and then transformed into $y^{18} - 12y - 146 = 0$.

Sometimes, by theſe transformations, "*Surds are taken away.*" As for example,

The equation $x^3 - p\sqrt{a} \times x^2 + qx - r\sqrt{a} = 0$, by putting $y = \sqrt{a} \times x$, or $x = \frac{y}{\sqrt{a}}$, is transformed into this equation,

$\frac{y^3}{a\sqrt{a}} - p\sqrt{a} \times \frac{y^2}{a} + q \times \frac{y}{\sqrt{a}} - r\sqrt{a} = 0$.

Which by multiplying all the terms by $a\sqrt{a}$, becomes $y^3 - py^2 + qay - ra^2 = 0$, an equation free of ſurds. But in order to make this ſucceed, the ſurd $(\sqrt{a})$ muſt enter the alternate terms beginning with the ſecond.

§ 32.

§ 32. An equation, as $x^3 - px^2 + qx - r = 0$, *may be transformed into one whoſe roots ſhall be the quantities reciprocal of* $x$; by ſuppoſing $y = \frac{1}{x}$, and $y = \frac{z}{r}$, or, (by one ſuppoſition) $x = \frac{r}{z}$, becomes $z^3 - qz^2 + prz - r^3 = 0$.

In the equation of $y$, it is manifeſt that the order of the coefficients is inverted; ſo that if the ſecond term had been wanting in the propoſed equation, the laſt but one ſhould have been wanting in the equations of $y$ and $z$. If the third had been wanting in the equation propoſed, the laſt but two had been wanting in the equations of $y$ and $z$.

Another uſe of this transformation is, that "*the greateſt root in the one is transformed into the leaſt root in the other.*" For ſince $x = \frac{1}{y}$, and $y = \frac{1}{x}$, it is plain that when the value of $x$ is greateſt, the value of $y$ is leaſt, and converſely.

How an equation is transformed ſo as to have all its roots affirmative, ſhall be explained in the following chapter.

CHAP.

## CHAP. IV.

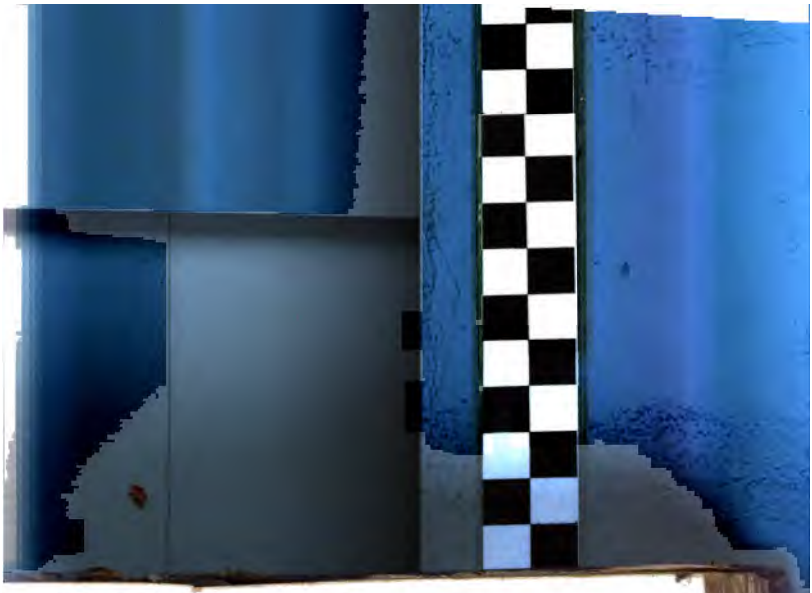
### Of finding the Roots of Equations when two or more of the Roots are equal to each other.

§ 33. BEFORE we proceed to explain how to reſolve equations of all ſorts, we ſhall firſt demonſtrate "*how an equation that has two or more roots equal, is depreſſed to a lower dimenſion*;" and its reſolution made, conſequently, more eaſy. And ſhall endeavour to explain the grounds of this and many other rules we ſhall give in the remaining part of this Treatiſe, in a more ſimple and conciſe manner than has hitherto been done.

In order to this, we muſt look back to § 24. where we find that if any equation, as $x^3 - px^2 + qx - r = 0$, is propoſed, and you are to tranſform it into another that ſhall have its roots leſs than the values of $x$ by any given difference, as $e$, you are to aſſume $y = x - e$, and ſubſtituting for $x$ its value $y + e$, you find the tranſformed equation,

$$\left.\begin{array}{rrrr} y^3 + & 3y^2 + & 3e^2y + & e^3 \\ - & py^2 - & 2pey - & pe^2 \\ & + & qy + & qe \\ & & - & r \end{array}\right\} = 0.$$

Where





## HAP. IV.

### he Roots of Equation or more of the Roo to each other.

E we proceed to explain ho lve equations of all ſorts, w ſtrate "*how an equation ha roots equal, is depreſſed to* and its reſolution made, ea eaſy. And ſhall endeavour t nds of this and many othe e in the remaining part of thi ore ſimple and conciſe manne been done.

s, we muſt look back to § 1 at if any equation, as $x^3 - p$ ropoſed, and you are to tran ther that ſhall have its roo es of $x$ by any given difference, aſſume $y = x - e$, and ſubſti alue $y + e$, you find the tran-

$$\left.\begin{matrix} {}^{3} + 3e^{2}y + e^{3} \\ {}^{2} - 2ey - e^{2} \\ + qy + qe \\ - r \end{matrix}\right\} = 0.$$

Where



Where we are to obſerve,

1° That the laſt term $(e^3 - pe^2 + qe - r)$ is the very equation that was propoſed, having $e$ in place of $x$.

2° The coefficient of the laſt term but one is $3e^2 - 2pe + q$, which is the quantity that ariſes by multiplying every term of the laſt coefficient $e^3 - pe^2 + qe - r$ by the index of $e$ in each term, and dividing the product $3e^3 - 2pe^2 + qe$ by the quantity $e$ that is common to all the terms.

3° The coefficient of the laſt term but two is $3e - p$, which is the quantity that ariſes by multiplying every term of the cofficient laſt found $(3e^2 - 2pe + q)$ by the index of $e$ in each term, and dividing the whole by $2e$.

§ 34. Theſe ſame obſervations extend to equations of all dimenſions. If it is the biquadratic $x^4 - px^3 + qx^2 - rx + s = 0$ that is propoſed, then by ſuppoſing $y = x - e$, it will be transformed into this other,

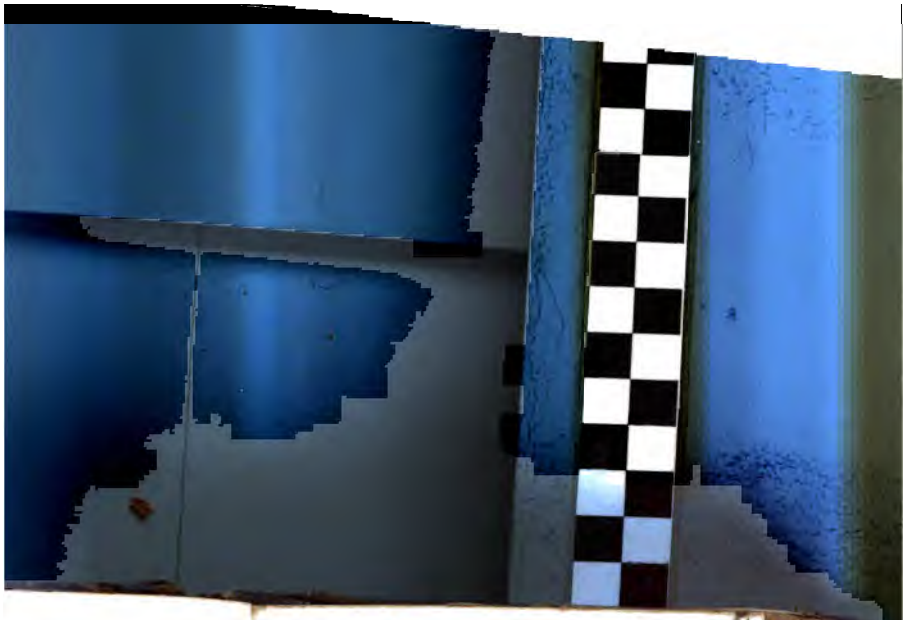
$$\left.\begin{matrix} y^4 + 4ey^3 + 6e^2y^2 + 4e^3y + e^4 \\ - py^3 - 3pey^2 - 3pe^2y - pe^3 \\ + qy^2 + 2qey + qe^2 \\ - ry - re \\ + s \end{matrix}\right\} = 0.$$

Where again it is obvious that the laſt term is the equation that was propoſed, having $e$ in place of $x$. That the laſt term but one has

for its coefficient the quantity that arises by multiplying the terms of the last quantity by the indices of $e$ in each term, and dividing the product by $e$. That the coefficient of the last term but two (*viz.* $6e^2 - 3pe + q$) is deduced in the same manner from the term immediately following; that is, by multiplying every term of $4e^3 - 3pe^2 + 2qe - r$ by the index of $e$ in that term, and dividing the whole by $e$ multiplied into the index of $y$ in the term sought, that is, by $e \times 2$. And the next term is $4e - p = \frac{6e^2 \times 2 - 3pe \times 1}{3e}$.

The demonstration of this may easily be made general by the Theorem for finding the powers of a binomial, since the transformed equation consists of the powers of the binomial $y+e$ that are marked by the indices of $e$ in the last term, multiplied each by their coefficients $1$, $-p$, $+q$, $-r$, $+s$, &c. respectively.

§ 35. From the last two articles we can easily find the terms of the transformed equation without any evolution. The last term is had by substituting $e$ instead of $x$ in the proposed equation; the next term, by multiplying every part of that last term by the index of $e$ in each part, and dividing the whole by $e$; and the following terms in the manner described in the foregoing article; the respective divisors being





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$pe^2 + 2qe - r$ by the index
m, and dividing the whole by
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being the quantity $e$ multiplied by the index of $y$ in each term.

The demonſtration for finding when two or more roots are equal will be eaſy, if we add to this, that "*when the unknown quantity enters all the terms of any equation, then one of its values is equal to nothing.*" As in the equation $x^3 - px^2 + qx = 0$, where $x - 0 = 0$ being one of the ſimple equations that produce $x^3 - px^2 + qx = 0$, it follows that one of the values of $x$ is 0. In like manner two of the values of $x$ are equal to nothing in this equation $x^3 - px^2 = 0$; and three of them vaniſh in the equation $x^4 - px^3 = 0$.

It is alſo obvious (*converſely*) that "if $x$ does not enter all the terms of the equation, *i. e.* if the laſt term be not wanting, then none of the values of $x$ can be equal to nothing;" for if every term be not multiplied by $x$, then $x-0$ cannot be a diviſor of the whole equation, and conſequently 0 cannot be one of the values of $x$. If $x^2$ does not enter into all the terms of the equation, then two of the values of $x$, cannot be equal to nothing. If $x^3$ does not enter into all the terms of the equation, then three of the values of $x$ cannot be equal to nothing, *&c.*

§ 36. Suppoſe now that two values of $x$ are equal to one another, and to $e$; then it is plain that two values of $y$ in the tranſformed equation

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If it is the biquadr
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$$- py^3$$

$$4e^3 - 3pe^2 + 2qe - r$$
$$4x^3 - 3px^2 + 2qx - r$$





*l* to *nothing*: ſince $y = z - \epsilon$,
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equation, *viz* $\epsilon^3 - p\epsilon^2 + q\epsilon - r$
nd ſince two values of $y$ vaniſh,
ut one, *viz.* $3\epsilon^2 y - 2py + q$
he ſame time. So that $y^2$-
But, by ſuppoſition, $\epsilon = z$;
two values of $x$, in the equa-
$-r = 0$, are equal, it follows,
$q = 0$. And thus "the pro-
preſſed to a quadratic that has
qual to one of the roots of that

uadratic that is propoſed, viz.
$+ s = 0$, and two of its roots
uppoſing $\epsilon = x$, two of the va-
niſh, and the equation of § 31
o this form,

$$\left.\begin{matrix} 4\epsilon y^3 + 6\epsilon^2 y^2 \\ y^3 - 3p\epsilon y^2 \\ + qy^2 \end{matrix}\right\} + s = 0.$$ So that

$-r = 0$; or, because $s = 0$,
$-r = 0$.

In



In general, when two values of $x$ are equal to each other, and to $\epsilon$, the two laſt terms of the transformed equation vaniſh: and conſequently, "if you multiply the terms of the propoſed equation by the indices of $x$ in each term, the quantity that will ariſe will be $= 0$, and will give an equation of a lower dimenſion than the propoſed, that ſhall have one of its roots equal to one of the roots of the propoſed equation."

That the laſt two terms of the equation vaniſh when the values of $x$ are ſuppoſed equal to each other, and to $\epsilon$, will alſo appear by conſidering, that ſince two values of $y$ then become equal to nothing, the product of the values of $y$ muſt vaniſh, which is equal to the laſt term of the equation; and becauſe two of the four values of $y$ are equal to nothing, it follows alſo that one of any three that can be taken out of theſe four muſt be $= 0$; and therefore, the products made by multiplying any three muſt vaniſh; and conſequently the coefficient of the laſt term but one, which is equal to the ſum of theſe products, muſt vaniſh.

§ 37. After the ſame manner, if there are three equal roots in the biquadratic $x^4 - px^3 + qx^2 - rx + s = 0$, and if $\epsilon$ be equal to one of them; three values of $y\ (= x - \epsilon)$ will vaniſh, and conſequently $y^3$ will enter all the terms of

the transformed equation; which will have this form,

$$\left.\begin{matrix} y^4 + 4Qy^1 \\ - fy^2 \end{matrix}\right\} *** = 0.$$ So that here $6e^2 - 3pe + q = 0$; or, since $e = x$, therefore, $6x^2 - 3px + q = 0$: and one of the roots of this quadratic will be equal to one of the roots of the propoſed biquadratic.

In this caſe, two of the roots of the cubic equation $4x^3 - 3px^2 + 2qx - r = 0$ are roots of the propoſed biquadratic, becauſe the quantity $6x^2 - 3px + q$ is deduced from $4x^3 - 3px^2 + 2qx - r$, by multiplying the terms by the indexes of $x$ in each term.

In general, "whatever is the number of equal roots in the propoſed equation, they will all remain but one in the equation that is deduced from it, by multiplying all the terms by the indexes of $x$ in them; and they will all remain but two in the equation deduced in the ſame manner from That;" and ſo of the reſt.

§ 38. What we obſerved of the coefficients of equations transformed by ſuppoſing $y = x - e$, leads to this eaſy demonſtration of this Rule; and will be applied in the next chapter to demonſtrate the Rules for finding the limits of equations.

It is obvious however, that though we make

ed equation; which will have

$+ 4ey^3 \} * * * = 0$. So that here
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$= 0$; or, since $e = x$, therefore,
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two of the roots of the cubic
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the ſame reaſoning extends to all other equations.

It is a conſequence alſo of what has been demonſtrated, that "if two roots of any equation, as $x^3 - px^2 + qx - r = 0$, are equal, then multiplying the terms by any arithmetical ſeries, as $a + 3b$, $a + 2b$, $a + b$, $a$, the product will be $= 0$.

For ſince $ax^3 - apx^2 + aqx - ar = 0$; and $3x^2 - 2px + q \times bx = 0$, it follows that $ax^3 + 3bx^3 - apx^2 - 2bpx^2 + aqx + bqx - ar = 0$. Which is the product that ariſes by multiplying the terms of the propoſed equation by the terms of the ſeries, $a + 3b$, $a + 2b$, $a + b$, $a$; which may repreſent any arithmetical progreſſion.

## CHAP. V.

### Of the Limits of Equa

§ 39. WE now proceed to sh
discover the limits of
equations, by which their solution
cilitated.

Let any equation, as $x^3 - px^2 +$
be proposed; and transform it, as
the equation

$$\left.\begin{matrix} y^3 + 3ey^2 + 3e^2y + e^3 \\ - py^2 - 2pey - pe^2 \\ + qy + qe \\ - r \end{matrix}\right\} =$$

Where the values of $y$ are less than
tive values of $x$ by the difference
suppose $e$ to be taken such as to m
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$e^3 - pe^2 + qe - r$, $3e^2 - 2pe + q$, $3e$
there being no variation of the sig
equation, all the values of $y$ must be
and consequently, the quantity $e$, by
values of $x$ are diminished, must be gr
the greatest positive value of $x$: a
quently must be the limit of the roo
equation $x^3 - px^2 + qx - r = 0$.

## CHAP. V.

### Limits of EQUATIONS.

now proceed to ſhew how to
iſcover the limits of the roots of
which their ſolution is much fa-

tion, as $x^3 - px^2 + qx - r = 0$,
id transform it, as above, into

$$\left.\begin{matrix} y^3 + 3e^2y + e^3 \\ -2pey - pe^2 \\ +qy + qe \\ -r \end{matrix}\right\} = 0.$$

s of $y$ are leſs than the reſpec-
by the difference $e$. If you
taken ſuch as to make all the
e equation of $y$, poſitive, viz.
$3e^2 - 2pe + q$, $3e - p$; then
riation of the ſigns in the
lues of $y$ muſt be negative;
he quantity $e$, by which the
niſhed, muſt be greater than
e value of $x$: and conſe-
limit of the roots of the
$qx - r = 0$.

It



It is ſufficient therefore, in order to find the limit, to "enquire what quantity ſubſtituted for $x$ in each of theſe expreſſions $x^3 - px^2 + qx - r$, $3x^2 - 2px + q$, $3x - p$, will give them all poſitive;" for that quantity will be the limit required.

How theſe expreſſions are formed from one another, was explained in the beginning of the laſt chapter.

### EXAMPLE.

§ 40. If the equation $x^5 - 2x^4 - 10x^3 + 30x^2 + 63x + 120 = 0$ is propoſed; and it is required to determine the limit that is greater than any of the roots; you are to enquire what integer number ſubſtituted for $x$ in the propoſed equation, and following equations deduced from it by § 35, will give, in each, a poſitive quantity.

$$5x^4 - 8x^3 - 30x^2 + 60x + 63$$
$$5x^3 - 6x^2 - 15x + 15$$
$$5x^2 - 4x - 5$$
$$5x - 2.$$

The leaſt integer number which gives each of theſe poſitive, is 2; which therefore is the limit of the roots of the propoſed equation; or a number that exceeds the greateſt poſitive root.

If

If the limit of the *negative* roots is required, you may, by § 23, change the negative into poſitive roots, and then proceed as before to find their limits. Thus, in the example, you will find that $-\frac{2}{3}$ is the limit of the negative roots. So that the five roots of the propoſed equation are betwixt $-\frac{2}{3}$ and $+2$.

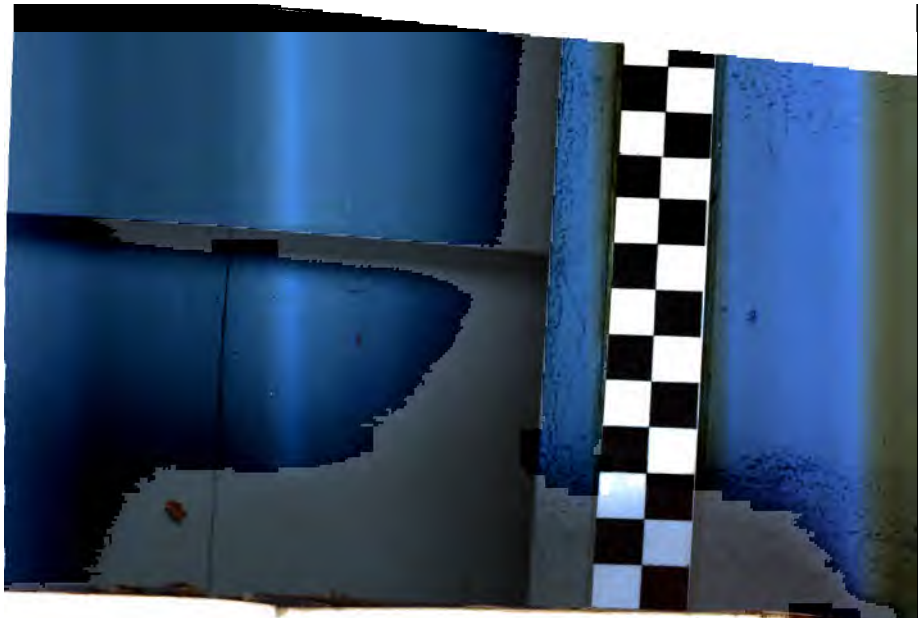
§ 41. Having found the limit that ſurpaſſes the greateſt poſitive root, call it $m$. And if you aſſume $y = m - x$, and for $x$ ſubſtitute $m - y$, the equation that will ariſe will have all its roots poſitive; becauſe $m$ is ſuppoſed to ſurpaſs all the values of $x$, and conſequently $m - x\ (= y)$ muſt always be affirmative. And by this means, *any equation may be changed into one that ſhall have all its roots affirmative.*

Or if $-n$ repreſent the limit of the negative roots, then by aſſuming $y = x + n$, the propoſed equation ſhall be transformed into one that ſhall have all its roots affirmative; for $+n$ being greater than any negative value of $x$, it follows, that $y = x + n$ muſt be always poſitive.

§ 42. "*The greateſt negative coefficent of any equation increaſed by unit, always exceeds the greateſt root of the equation.*"

To demonſtrate this, let the cubic $x^3 - px^2 - qx - r = 0$ be propoſed; where all the terms are negative except the firſt. Aſſuming $y = x - e$ it will be transformed into the following equation.

$y^3 - 3ey^2 + \ldots$ (A)





nit of the *negative* roots is required,
by § 23, change the negative into
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Thus, in the example, you will
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oſitive root, call it *m*. And if you
$-x$, and for $x$ ſubſtitute $m-y$
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auſe *m* is ſuppoſed to ſurpaſs all
*x*, and conſequently $m-x(=y)$
e affirmative. And by this means
*may be changed into one that ſhall*
*'s affirmative.*
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uſt be always poſitive.
*greateſt negative coefficient of any*
*by unit, always exceeds the greateſt*
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ite this, let the cubic $x^3-px^2$
propoſed; where all the terms
ept the firſt. Aſſuming $y=x-1$
rmed into the following equa-

(A)



$$(A)\left.\begin{array}{rrrr} y^3 & +3y^2 & +3e^2y & +e^3 \\ & -py^2 & -2pey & -pe^2 \\ & & +qy & -qe \\ & & & -r \end{array}\right\}=0.$$

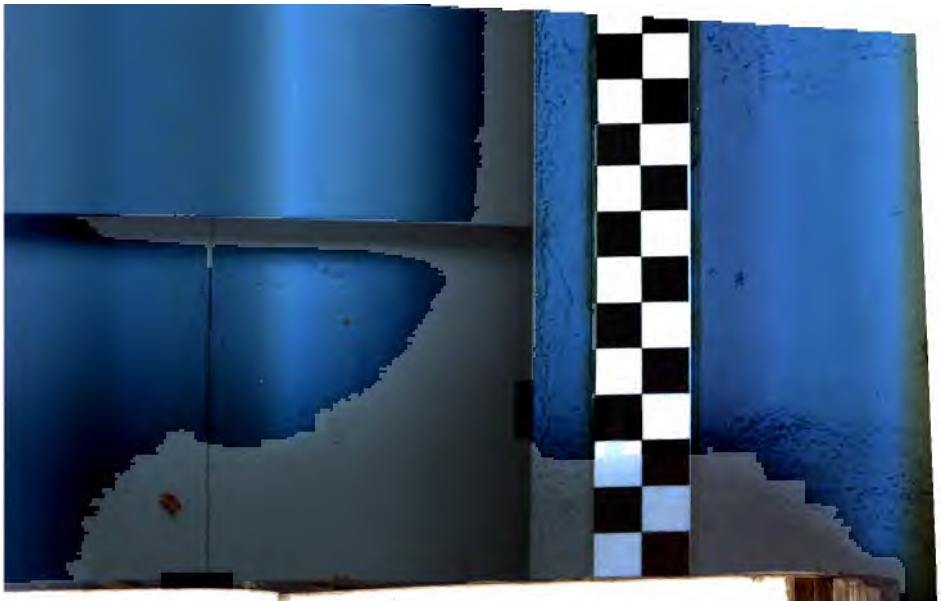
1°. Let us ſuppoſe that the coefficients $p, q, r$, are equal to each other; and if you alſo ſuppoſe $e=p+1$, then the laſt equation becomes

$$(B)\left.\begin{array}{rrrr} y^3 & +2py^2 & +p^2y & +1 \\ & +3y^2 & +3py & \\ & & +3y & \end{array}\right\}=0.$$

Where all the terms being poſitive, it follows that the values of $y$ are all negative, and that conſequently $e$, or $p+1$, is greater than the greateſt value of $x$ in the propoſed equation.

2°. If $q$ and $r$ be not $=p$, but leſs than it, and for $e$ you ſtill ſubſtitute $p+1$ (ſince the negative part $\left.\begin{array}{r} -qy-qe \\ -r \end{array}\right)$ becomes leſs, the poſitive remaining undiminiſhed) *a fortiori*, all the coefficients of the equation *(A)* become poſitive. And the ſame is obvious if $q$ and $r$ have poſitive ſigns, and not negative ſigns, as we ſuppoſed. It appears therefore, "that, if, in any cubic equation, $p$ be the greateſt negative coefficient, then $p+1$ muſt ſurpaſs the greateſt value of $x$."

§ 43. 3°. By the ſame reaſoning it appears, that if $q$ be the greateſt negative coefficient of the





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is ſuppoſed $= r+1$, then all
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ave ſaid of the *cubic* equation
$-r=0$, is eaſily applicable to

conclude that "the greateſt
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obſerved at the ſame time, that
tive coefficient increaſed by
om the *neareſt* limit: that is
the Rule in the 39th article.

§ 44



§ 44. Having ſhewn in § 41. how to change any propoſed equation into one that ſhall have all its roots affirmative; we ſhall only treat of ſuch as have all their roots poſitive, in what remains relating to the limits of equations.

Any ſuch equation may be repreſented by $\overline{x-a}\times\overline{x-b}\times\overline{x-c}\times\overline{x-d}$, &c.$=0$, whoſe roots are $a$, $b$, $c$, $d$, &c.

And of all ſuch equations two limits are eaſily diſcovered from what precedes, *viz.* 0, which is leſs than the leaſt, and $e$, found according to § 39. which ſurpaſſes the greateſt root of the equation.

But beſides theſe, we ſhall now ſhew how "*to find other limits betwixt the roots themſelves.*" And, for this purpoſe, will ſuppoſe $a$ to be the leaſt root, $b$ the ſecond root, $c$ the third, and ſo on; it being arbitrary.

§ 45. If you ſubſtitute 0 in place of the unknown quantity, putting $x=0$, the quantity that will ariſe from that ſuppoſition is the laſt term of the equation, all the others, that involve $x$, vaniſhing.

If you ſubſtitute for $x$ a quantity leſs than the leaſt root $a$, the quantity reſulting will have the ſame ſign as the laſt term; that is, will be poſitive or negative according as the equation is of an even or odd number of dimenſions. For all the factors $x-a$, $x-b$, $x-c$, &c. will be negative, and their product will be *poſitive*

or

or *negative* according as their number is *even* or *odd*.

If you ſubſtitute for $x$ a quantity greater than the leaſt root $a$, but leſs than all the other roots, then the ſign of the quantity reſulting will be contrary to what it was before; becauſe one factor $(x - a)$ becomes now poſitive, all the others remaining negative as before.

If you ſubſtitute for $x$ a quantity greater than the two leaſt roots, but leſs than all the reſt, both the factors $x - a$, $x - b$, become poſitive, and the reſt remain as they were. So that the whole product will have the ſame ſign as the laſt term of the equation. Thus ſucceſſively placing inſtead of $x$ quantities that are limits betwixt the roots of the equation, the quantities that reſult will have alternately the ſigns $+$ and $-$. And, *converſely*, "if you find quantities which ſubſtituted in place of $x$ in the propoſed equation, to give alternately poſitive and negative reſults, thoſe quantities are the limits of that equation."

It is uſeful to obſerve, that, in general, "when, by ſubſtituting any two numbers for $x$ in any equation, the reſults have contrary ſigns, one or more of the roots of the equation muſt be betwixt thoſe numbers." Thus, in the equation $x^3 - 2x^2 - 5 = 0$, if you ſubſtitute 2 and 3 for $x$, the reſults are $-5$, $+4$; whence it follows that the roots are betwixt 2

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and 3: for when theſe reſults have different ſigns, one or other of the factors which produce the equations muſt have changed its ſign; ſuppoſe it is $x = e$, then it is plain that $e$ muſt be betwixt the numbers ſuppoſed equal to $x$.

§ 46. Let the cubic equation $x^3 - px^2 + qx - r = 0$ be propoſed, and let it be transformed, by aſſuming $y = x - e$, into the equation

$$\left.\begin{array}{r} y^3 + 3ey^2 + 3e^2y + e^3 \\ - py^2 - 2pey - pe^2 \\ + qy + qe \\ - r \end{array}\right\} = 0.$$

Let us ſuppoſe $e$ equal ſucceſſively to the three values of $x$, beginning with the leaſt value; and becauſe the laſt term $e^3 - pe^2 + qe - r$ will vaniſh in all theſe ſuppoſitions, the equation will have this form,

$$\left.\begin{array}{r} y^3 + 3ey^2 + 3e^2y \\ - py - 2pe \\ + q \end{array}\right\} = 0,$$

where the laſt term $3e^2 - 2pe + q$ is, from the nature of equations, produced of the remaining values of $y$, or of the exceſſes of two other values of $x$ above what is ſuppoſed equal to $e$; ſince always $y = x - e$. Now,

1°. If $e$ be equal to the leaſt value of $x$, then thoſe two exceſſes being both poſitive, they will give a poſitive product, and conſequently $3e^2 - 2pe + q$ will be, in this caſe, poſitive.

2°.

2°. If $e$ be equal to the ſecond value of $x$, then, of thoſe two exceſſes one being negative and one poſitive, their product $3e^2 - 2pe + q$, will be negative.

3°. If $e$ be equal to the third and greateſt value of $x$, then the two exceſſes being both negative, their product $3e^2 - 2pe + q$ is poſitive. Whence,

If in the equation $3e^2 - 2pe + q = 0$, you ſubſtitute ſucceſſively in the place of $e$, the three roots of the equation $e^3 - pe^2 + qe - r = 0$, the quantities reſulting will ſucceſſively have the ſigns $+, -, +$; and conſequently the three roots of the cubic equation are the limits of the roots of the equation $3e^2 - 2pe + q = 0$ (by § 45.) That is, the leaſt of the roots of the cubic is leſs than the leaſt of the roots of the other; the ſecond root of the cubic is a limit between the two roots of the other; and the greateſt root of the cubic is the limit that exceeds both the roots of the other.

§ 47. We have demonſtrated that the roots of the cubic equation $e^3 - pe^2 + qe - r = 0$ are limits of the quadratic $3e^2 - 2pe + q$; whence it follows *(converſely)* that the roots of the quadratic $3e^2 - 2pe + q = 0$ are the limits between the firſt and ſecond, and between the ſecond and third roots of the cubic $e^3 - pe^2 + qe - r = 0$. So that if you find the limit that exceeds the greateſt

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greateſt root of the cubic, by § 39. you will have (with 0, which is the limit leſs than any of the roots) four limits for the three roots of the propoſed cubic.

It was demonſtrated in § 35. how the quadratic $3e^2 - 2pe + q$ is deduced from the propoſed cubic $e^3 - pe^2 + qe - r = 0$, *viz.* by multiplying each term by the index of $e$ in it, and then dividing the whole by $e$; and what we have demonſtrated of cubic equations is eaſily extended to all others; ſo that we conclude, "that the laſt term but one of the transformed equation is the equation for determining the limits of the propoſed equation." Or, that the equation ariſing by multiplying each term by the index of the unknown quantity in it, is the equation whoſe roots give the limits of the propoſed equation; if you add to them the two mentioned in § 44.

§ 48. For the ſame reaſon, it is plain that the root of the ſimple equation $3e - p = 0$, (*i. e.* $\frac{1}{3}p$) is the limit between the two roots of the quadratic $3e^2 - 2pe + q = 0$. And, as $4e^3 - 3pe^2 + 2qe - r = 0$ gives three limits of the equation $e^4 - pe^3 + qe^2 - re + s = 0$, ſo the quadratic $6e^2 - 3pe + q = 0$ gives two limits that are betwixt the roots of the cubic $4e^3 - 3pe^2 + 2qe - r = 0$; and $4e - p = 0$ gives one limit that is betwixt the two roots of

the quadratic $6e^2 - 3pe + q = 0$. So that we have a compleat ſeries of theſe equations ariſing from a ſimple equation to the propoſed, each of which determines the limits of the following equation.

§ 49. If two roots in the propoſed equation are equal, then "the limit that ought to be betwixt them muſt, in this caſe, become equal to one of the equal roots themſelves." Which perfectly agrees with what was demonſtrated in the laſt chapter, concerning the Rule for finding the equal roots of equations.

And, the ſame equation that gives the limits, giving alſo one of the equal roots, when two or more are equal, it appears, that "if you ſubſtitute a limit in place of the unknown quantity in an equation, and, inſtead of a poſitive or negative reſult, it be found $= 0$, then you may conclude, that not only the limit itſelf is a root of the equation, but that there are two roots in that equation equal to it and to one another."

§ 50. It having been demonſtrated that the roots of the equation $x^3 - px^2 + qx - r = 0$ are the limits of the roots of the equation $3x^2 - 2px + q = 0$, the three roots of the cubic equation, which ſuppoſe to be $a$, $b$, $c$, ſubſtituted for $x$ in the quadratic $3x^2 - 2px + q$, muſt give the reſults poſitive and negative alternately.

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nately. Suppoſe theſe three reſults to be $+N$, $-M$, $+L$; that is, $3a^2 - 2pa + q = N$, $3b^2 - 2pb + q = -M$, $3c^2 - 2pc + q = L$; and ſince $a^3 - pa^2 + qa - r = 0$, and $3a^3 - 2pa^2 + qa = N \times a$, ſubtracting the former multiplied into 3 from the latter, the remainder is $pa^2 - 2qa + 3r = N \times a$. In the ſame manner $pb^2 - 2qb + 3r = -M \times b$, and $pc^2 - 2qc + 3r = +L \times c$. Therefore $px^2 - 2qx + 3r$ is ſuch a quantity that if, for $x$, you ſubſtitute in it ſucceſſively $a, b, c$, the reſults will be $+N \times a$, $-M \times b$, $+L \times c$. Whence $a, b, c$, are the limits of the equation $px^2 - 2qx + 3r = 0$ (by § 45.) and, *converſely*, the roots of the equation $px^2 - 2qx + 3r = 0$ are limits between the firſt and ſecond, and between the ſecond and third roots of the cubic $x^3 - px^2 + qx - r = 0$. Now the equation $px^2 - 2qx + 3r = 0$ ariſes from the propoſed cubic by multiplying the terms of this latter by the arithmetical progreſſion $0, -1, -2, -3$. And in the ſame manner it may be ſhewn that the roots of the equation $px^3 - 2qx^2 + 3rx - 4s = 0$ are limits of the equation $x^4 - px^3 + qx^2 - rx + s = 0$.

Or, multiply the terms of the equation

$x^3 - px^2 + qx - r = 0$

by $a + 3b, a + 2b, a + b, a$,

$ax^3 - apx^2 + aqx - ar \ (= 0)$

$+ 3bx^3 - 2bpx^2 + bqx \ (= 3x^2 - 2px + q \times bx)$.

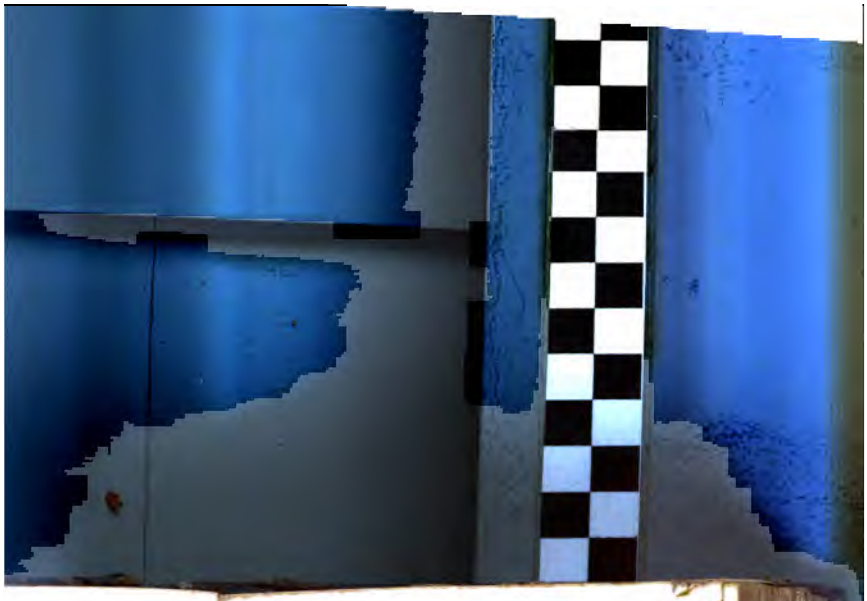
Any arithmetical ſeries where $a$ is the leaſt term and $b$ the common difference, and the products (if you ſubſtitute for $x$, ſucceſſively, $a$, $b$, $c$, the three roots of the propoſed cubic) ſhall be $+N\times bx$, $-M\times bx$, $+L\times bx$. For the firſt part of the product $a\times x^3-px^2+qx-r=0$; and $a$, $b$, $c$, being limits in the equation $3x^2-2px+q=0$, their ſubſtitution muſt give reſults $N$, $M$, $L$, alternately poſitive and negative.

*In general*, the roots of the equation $x^n-px^{n-1}+qx^{n-2}-rx^{n-3}+$, &c. $=0$ are limits of the roots of the equation $nx^{n-1}-\overline{n-1}\times px^{n-2}+\overline{n-2}\times qx^{n-3}-\overline{n-3}\times rx^{n-4}+$, &c. $=0$; or of any equation that is deduced from it by multiplying its terms by any arithmetical progreſſion $a\mp b$, $a\mp 2b$, $a\mp 3b$, $a\mp 4b$, &c. *And converſely*, the roots of this new equation will be limits of the propoſed equation.

$$x^n-px^{n-1}+qx^{n-2}-, \text{ \&c.} =0.$$

"*If any roots of the equation of the limits are impoſſible, then muſt there be ſome roots of the propoſed equation impoſſible.*" For as (in § 46.) the quantity $3e^2-2pe+q$ was demonſtrated to be equal to the product of the exceſſes of two values of $x$ above the third ſuppoſed equal to $e$; if any impoſſible expreſſion be found in thoſe exceſſes, then there will of conſequence be found impoſſible expreſſions in theſe two values of $x$.

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And "from this obſervation rules may be deduced for diſcovering when there are impoſſible roots in equations." Of which we ſhall treat afterwards.

§ 51. Beſides the method already explained, there are others by which limits may be determined, which the root of an equation cannot exceed.

Since the ſquares of all real quantities are affirmative, it follows, that "*the ſum of the ſquares of the roots of any equation muſt be greater than the ſquare of the greateſt root.*" And the ſquare root of that ſum will therefore be a limit that muſt exceed the greateſt root of the equation.

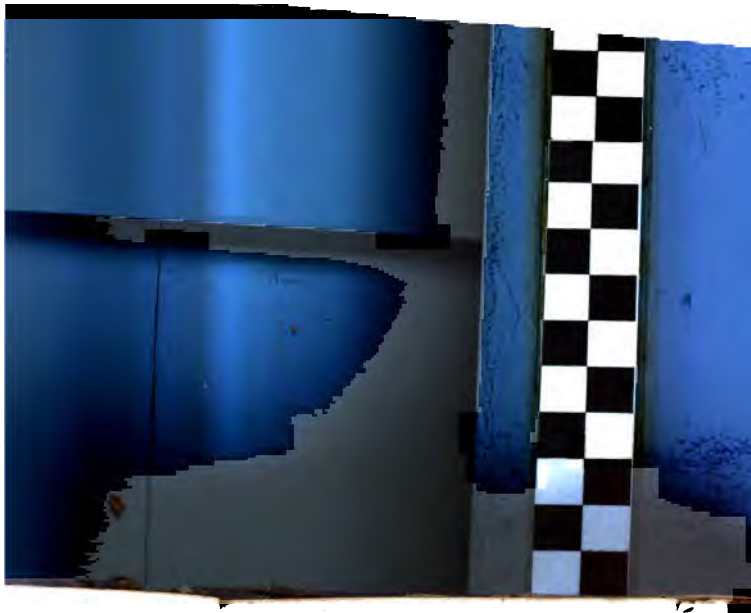
If the equation propoſed is $x^n - px^{n-1} + qx^{n-2} - rx^{n-3} +$, &c. $= 0$, then the ſum of the ſquares of the roots (by § 15.) will be $p^2 - 2q$. So that $\sqrt{p^2 - 2q}$ will exceed the greateſt root of that equation.

Or if you find, by § 16. the ſum of the 4th powers of the roots of the equation, and extract the biquadratic root of that ſum, it will alſo exceed the greateſt root of the equation.

§ 52. If you find a mean proportional between the ſum of the ſquares of any two roots, $a$, $b$, and the ſum of their biquadrates $(a^4 + b^4)$, this mean proportional will be $\sqrt{a^6 + a^2b^4 + a^4b^2 + b^6}$. And the ſum of the

cubes is $a^3+b^3$. Now ſince $a^2-2ab+b^2$ is the ſquare of $a-b$, it muſt be always poſitive; and if you multiply it by $a^2b^2$, the product $a^4b^2-2a^3b^3+a^2b^4$ will alſo be poſitive; and conſequently $a^4b^2+a^2b^4$ will be always greater than $2a^3b^3$. Add $a^6+b^6$, and we have $a^6+a^4b^2+a^2b^4+b^6$ greater than $a^6+2a^3b^3+b^6$; and extracting the root $\sqrt{a^6+a^4b^2+a^2b^4+b^6}$ greater than $a^3+b^3$. And the ſame may be demonſtrated of any number of roots whatever.

Now if you add the ſum of all the cubes taken *affirmatively* to their ſum with their *proper* ſigns, they will give double the ſum of the cubes of the affirmative roots. And if you ſubtract the ſecond ſum from the firſt, there will remain double the ſum of the cubes of the negative roots. Whence it follows, that "half the ſum of the mean proportional betwixt the ſum of the ſquares and the ſum of the biquadrates, and of the ſum of the cubes of the roots with their proper ſigns, exceeds the ſum of the cubes of the affirmative roots:" and "half their difference exceeds the ſum of the cubes of the negative roots." And by extracting the cube root of that ſum and difference, you will obtain limits that ſhall exceed the ſums of the affirmative and of the negative roots. And ſince it is eaſy, from what has been





$+b^3$. Now since $a^2-2ab+b^2$ i
$a-b$, it muſt be always poſitive;
multiply it by $a^2b^2$, the produc
$-a^3b^4$ will alſo be poſitive; and
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Add $a^5+b^5$, and we have $a^4+a$
greater than $a^6+2a^3b^3+b^6$;
the root $\sqrt[3]{a^6+a^4b^2+a^2b^4+b^6}$
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been already explained, to diminiſh the roots of an equation ſo that they all may become negative but one, it appears how by this means you may approximate very near to that root. But this does not ſerve when there are impoſſible roots.

Several other Rules like theſe might be given for limiting the roots of equations. We ſhall give one not mentioned by other Authors.

In a cubic $x^3-px^2+qx-r=0$ find $q^2-2pr$, and call it $e^4$; then ſhall the greateſt root of the equation always be greater than $\frac{e}{\sqrt[4]{3}}$, or $\sqrt[4]{\frac{e^4}{3}}$. And,

In any equation $x^n-px^{n-1}+qx^{n-2}-rx^{n-3}$ +, &c. $=0$ find $\frac{q^2-2pr+2s}{n}$, and extracting the root of the fourth power out of that quantity, it ſhall always be leſs than the greateſt root of the equation.

## CHAP. VI.

### Of the Reſolution of Equations, all whoſe Roots are commenſurate.

§ 53. IT was demonſtrated, in *Chap.* 2. that the laſt term of any equation is the product of its roots: from which it follows, that the roots of an equation, when commenſurable quantities, will be found among the diviſors of the laſt term. And hence we have for the reſolution of equations this eaſy

#### RULE.

*Bring all the terms to one ſide of the equation, find all the diviſors of the laſt term, and ſubſtitute them ſucceſſively for the unknown quantity in the equation. So ſhall that diviſor which, ſubſtituted in this manner, gives the reſult* =0, *be the root of the propoſed equation.*

For example, ſuppoſe this equation is to be reſolved,

$$\left.\begin{matrix} x^3 - 3ax^2 + 2a^2x - 2a^3b \\ - bx^2 + 3abx \end{matrix}\right\} = 0,$$

where the laſt term is $2a^3b$, whoſe ſimple literal

## CHAP. VI.

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Roots are commenſurate

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*be the root of the propoſed equa*

, ſuppoſe this equation is to be

$$\left.\begin{matrix} +2a^2x-2a^2b \\ +3abx \end{matrix}\right\}=0,$$

erm is $2a^2b$, whoſe ſimple liter-
ral



ral diviſors are $a$, $b$, $2a$, $2b$, each of which may be taken either poſitively or negatively: but as here we find there are variations of ſigns in the equation, we need only take them poſitively. Suppoſe $x=a$ the firſt of the diviſors, and ſubſtituting $a$ for $x$, the equation becomes

$$\left.\begin{matrix} a^3-3a^3+2a^3-2a^2b \\ -a^2b+3a^2b \end{matrix}\right\} \text{ or, } 3a^3-3a^3+3a^2b-3a^2b=0.$$

So that, the whole vaniſhing, it follows that $a$ is one of the roots of the equation.

After the ſame manner, if you ſubſtitute $b$ in place of $x$, the equation is

$$\left.\begin{matrix} b^3-3ab^2+2a^2b-2a^2b \\ -b^3+3ab^2 \end{matrix}\right\}=0,$$

which vaniſhing ſhews $b$ to be another root of the equation.

Again, if you ſubſtitute $2a$ for $x$, you will find all the terms deſtroy one another ſo as to make the ſum $=0$. For it will then be

$$\left.\begin{matrix} 8a^3-12a^3+4a^3-2a^2b \\ -4a^2b+6a^2b \end{matrix}\right\}=0.$$

Whence we find that $2a$ is the third root of the equation. Which, after the firſt two ($+a$, $+b$) had been found, might have been collected from this, that the laſt term being the product of the three roots, $+a$, $+b$ being known, the

the third muſt neceſſarily be equal to the laſt term divided by the product $ab$, that is, $= \frac{2a^2b}{ab} = 2a$.

Let the roots of the cubic equation

$x^3 - 2x^2 - 33x + 90 = 0$ be required.

And firſt the diviſors of 90 are found to be 1, 2, 3, 5, 6, 9, 10, 15, 18, 30, 45, 90. If you ſubſtitute 1 for $x$, you will find $x^3 - 2x^2 - 33x + 90 = 56$; ſo that 1 is not a root of the equation. If you ſubſtitute 2 for $x$, the reſult will be 24: but putting $x = 3$, you have

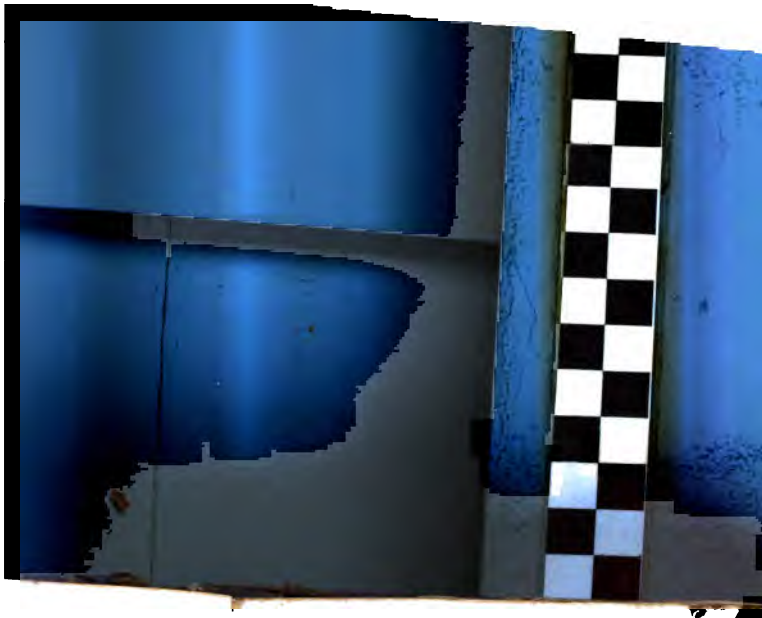
$x^3 - 2x^2 - 33x + 90 = 27 - 18 - 99 + 90 = 117 - 117 = 0$.

So that 3 is one of the roots of the propoſed equation. The other affirmative root is $+5$; and after you find it, as it is manifeſt from the equation, that the other root is negative, you are not to try any more diviſors taken poſitively, but to ſubſtitute them, negatively taken, for $x$: and thus you find that $-6$ is the third root. For putting $x = -6$, you have

$x^3 - 2x^2 - 33x + 90 = -216 - 72 + 198 + 90 = 0$.

This laſt root might have been found by dividing the laſt term 90, having its ſign changed, by 15, the product of the two roots already found.

§ 55. When one of the roots of an equation is found, in order to find the reſt with leſs trouble, divide the propoſed equation by the ſimple equation which you are to deduce from the root already





t neceſſarily be equal to the laſt
by the product *ab*, that is, =

of the cubic equation
$3x+90=0$ be required.
iviſors of 90 are found to be
10, 15, 18, 30, 45, 90. If you
$x$, you will find $x^3-2x^2-3x$
hat 1 is not a root of the equa-
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ing $x=3$, you have
$=27-18-99+90=117-117=0$.
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are to deduce from the root
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already found, and the quotient ſhall give an equation of a degree lower than the propoſed; whoſe roots will give the remaining roots required.

As for example, the root $+3$, firſt found, gave $x=3$ or $x-3=0$, whence dividing thus,

$x-3)\ x^3-2x^2-33x+90\ (x^2+x-30$
$x^3-3x^2$
$x^2-33x+90$
$x^2-3x$
$-30x+90$
$-30x+90$
$0\quad 0$

The quotient ſhall give a quadratic equation $x^2+x-30=0$, which muſt be the product of the other two ſimple equations from which the cubic is generated, and whoſe roots therefore muſt be two of the roots of that cubic.

Now the roots of that quadratic equation are eaſily found by *Chap. 13. Part* I. to be $+5$ and $-6$. For,

$x^2+x=30$;

add $\frac{1}{4}$ ... $x^2+x+\frac{1}{4}=30+\frac{1}{4}=\frac{121}{4}$,

$\surd$ ..... $x+\frac{1}{2}=\pm\surd\frac{121}{4}=\pm\frac{11}{2}$,

and .... $x=\pm\frac{11}{2}-\frac{1}{2}=+5$, or $-6$.

§ 56.

§ 56. After the ſame manner, if the biquadratic $x^4-2x^3-25x^2+26x+120=0$ is to be reſolved; by ſubſtituting the diviſors of 120 for $x$, you will find that $+3$, one of thoſe diviſors, is one of the roots; the ſubſtitution of 3 for $x$ giving $81-54-225+78+120=279-279=0$. And therefore dividing the propoſed equation by $x-3$, you muſt enquire for the roots of the cubic $x^3+x^2-22x-40=0$, and finding that $+5$, one of the diviſors of 40, is one of the roots, you divide that cubic by $x-5$, and the quotient gives the quadratic $x^2+6x+8=0$, whoſe two roots are $-2$, $-4$. So that the four roots of the biquadratic are $+3$, $+5$, $-2$, $-4$.

§ 57. This Rule ſuppoſes that you can find all the diviſors of the laſt term; which you may always do thus.

"*If it is a ſimple quantity, divide it by its leaſt diviſor that exceeds unit, and the quotient again by its leaſt diviſor, proceeding thus till you have a quotient that is not diviſible by any number greater than unit.* This quotient, with theſe diviſors, are the firſt or *ſimple diviſors* of the quantity. And the products of the multiplication of any 2, 3, 4, *&c.* of them are the *compound diviſors.*"

As, to find the diviſors of 60; firſt I divide by 2, and the quotient 30 again by 2, then the next

next quotient 15 by 3, and the quotient of this diviſion 5 is not farther diviſible by any integer above units; ſo that

The ſimple diviſors are . . . . . 2, 2, 3, 5.
The products of two, . . . . . 4, 6, 10, 15.
The products of three, . . . . . 12, 20, 30.
The product of all four, . . . . . 60.

The diviſors of 90 are found after the ſame manner.

Simple diviſors, . . . . . 2, 3, 3, 5.
The products of two, . . . . 6, 9, 10, 15.
The products of three, . . . . 18, 30, 45.
The product of all four, . . . . . 90.

The diviſors of $21abb$.

The ſimple diviſors, . . . . . 3, 7, $a$, $b$, $b$.
The products of two, 21, $3a$, $3b$, $7a$, $7b$, $ab$, $bb$.
The products of three, $21a$, $21b$, $3ab$, $3bb$. $7ab$, $7bb$, $abb$.
The products of four, $21ab$, $21bb$, $3abb$, $7abb$.
The product of the five, . . . . . $21ab$.

§ 58. But as the laſt term may have very many diviſors, and the labour may be very great to ſubſtitute them all for the unknown quantity, we ſhall now ſhow how it may be abridged, by limiting to a ſmall number the diviſors you are to try. And firſt it is plain, from § 42. that "any diviſor that exceeds the greateſt

greateſt negative coefficient by unity is to be neglected." Thus in reſolving the equation $x^4 - 2x^3 - 25x^2 + 26x + 120 = 0$, as 25 is the greateſt negative coefficient, we conclude that the diviſors of 120 that exceed 26 may be neglected.

But the labour may be ſtill abridged, if we make uſe of the Rule in § 39; that is, if we find the number, which ſubſtituted in theſe following expreſſions,

$$x^4 - 2x^3 - 25x^2 + 26x + 120$$
$$2x^3 - 3x^2 - 25x + 13,$$
$$6x^2 - 6x - 25,$$
$$2x - 1,$$

will give in them all a poſitive reſult: for that number will be greater than the greateſt root, and all the diviſors of 120 that exceed it may be neglected.

That this inveſtigation may be eaſier, we ought to begin always with that expreſſion, where the negative roots ſeem to prevail moſt; as here in the quadratic expreſſion $6x^2 - 6x - 25$; where finding that 6 ſubſtituted for $x$ gives that expreſſion poſitive, and gives all the other expreſſions at the ſame time poſitive, I conclude that 6 is greater than any of the roots, and that all the diviſors of 120 that exceed 6 may be neglected.

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Thus in reſolving the equation
$x^3+26x+120=0$, as 25 is the
ive coefficient, we conclude that
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ons,

$x^3-25x^2+26x+120$
$x^2-25x+13$,
$x-25$,

n all a poſitive reſult: for that
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ime time poſitive, I conclude
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f 120 that exceed 6 may be

If





If the equation $x^3+11x^2+10x-72=0$ is propoſed, the Rule of § 42 does not help to abridge the operation; the laſt term itſelf being the greateſt negative term. But, by § 39. we enquire what number ſubſtituted for $x$ will give all theſe expreſſions poſitive:

$$x^3+11x^2+10x-72,$$
$$3x^2+22x+10,$$
$$3x+11.$$

Where the labour is very ſhort, ſince we need only attend to the firſt expreſſion; and we ſee immediately that 4 ſubſtituted for $x$ gives a poſitive reſult, whence all the diviſors of 72 that exceed 4 are to be rejected; and thus by a few trials we find that $+2$ is the poſitive root of the equation. Then dividing the equation by $x-2$, and reſolving the quadratic equation that is the quotient of the diviſion, you find the other two roots to be $-9$, and $-4$.

§ 59. But there is another method that reduces the diviſors of the laſt term, that can be uſeful, ſtill to more narrow limits.

Suppoſe the cubic equation $x^3-px^2+qx-r=0$ is propoſed to be reſolved. Transform it to an equation whoſe roots ſhall be leſs than the values of $x$ by unity, aſſuming $y=x-1$. And the laſt term of the tranſformed equation will be $1-p+q-r$; which is found by ſubſtituting unit, the difference of $x$ and $y$, for $x$,

in

in the propoſed equation; as will eaſily appear from § 24. where, when $y = x - e$, the laſt term of the transformed equation was $e^3 - pe^2 + qe - r$.

Transform again the equation $x^3 - px^2 + qx - r = 0$, by aſſuming $y = x + 1$, into an equation whoſe roots ſhall exceed the values of $x$ by unit, and the laſt term of the transformed equation will be $-1 - p - q - r$, the ſame that ariſes by ſubſtituting $-1$, the difference betwixt $x$ and $y$, for $x$, in the propoſed equation.

Now the values of $x$ are ſome of the diviſors of $r$, which is the term left when you ſuppoſe $x = 0$; and the values of the $y$'s are ſome of the diviſors of $+1 - p + q - r$, and of $-1 - p - q - r$, reſpectively. And theſe values are in arithmetical progreſſion increaſing by the common difference unit; becauſe $x - 1$, $x$, $x + 1$, are in that progreſſion. And it is obvious the ſame reaſoning may be extended to any equation of whatever degree. So that this gives a general method for the reſolution of equations whoſe roots are commenſurable.

RULE.

"*Subſtitute in place of the unknown quantity ſucceſſively the terms of the progreſſion* 1, 0, $-1$, &c. *and find all the diviſors of the ſums that reſult; then take out all the arithmetical progreſſions you can find among theſe diviſors, whoſe*

oſed equation; as will eaſily appear
where, when $y = x - e$, the laſt term
ormed equation was $e^4 - pe^3 + qe^2 - re$
again the equation $x^4 - px^3 + qx^2 - rx$
ſſuming $y = x + 1$, into an equa-
ots ſhall exceed the values of x
the laſt term of the transformed
be $-1 - p - q - r$, the ſame
ſubſtituting $-1$, the difference
$y$, for $x$, in the propoſed equa-

ues of $x$ are ſome of the diviſors
the term left when you ſuppoſe
values of the $y$'s are ſome of the
$-p+q-r$, and of $-1-p-q-r$,
And theſe values are in arithme-
increaſing by the common dif-
ecauſe $x-1$, $x$, $x+1$, are in
And it is obvious the ſame
e extended to any equation of
So that this gives a general
reſolution of equations whoſe
nſurable.

RULE.

*of the unknown quantity ſuc-*
*erms of the progreſſion* 1, 0,
*find all the diviſors of the laſt*
*n take out all the arithmetical*
*can find among theſe diviſors,*
*whoſe*



*whoſe common difference is unit; and the values of x will be among the diviſors ariſing from the ſubſtitutions of $x = 0$ that belong to theſe progreſſions.*" The values of $x$ will be affirmative when the arithmetical progreſſion increaſes, but negative when it decreaſes.

## EXAMPLE.

§ 60. Let it be required to find one of the roots of the equation $x^3 - x^2 - 10x + 6 = 0$. The operation is thus:

| *Suppoſit.* | *Reſult.* | *Diviſors.* | *Arith. prog. decr.* |
|---|---|---|---|
| $x = 1$ | $-4$ | 1, 2, 4 | 4 |
| $x = 0$ | $x^3 - x^2 - 10x + 6 = +6$ | 1, 2, 3, 6 | 3 gives $x = -3$ |
| $x = -1$ | $+14$ | 1, 2, 7, 14 | 2 |

Where the ſuppoſitions of $x = 1$, $x = 0$, $x = -1$ give the quantity $x^3 - x^2 - 10x + 6$ equal to $-4$, 6, 14; among whoſe diviſors we find only one arithmetical progreſſion, 4, 3, 2; the term of which oppoſite to the ſuppoſition of $x = 0$, being 3, and the ſeries decreaſing, we try if $-3$ ſubſtituted for $x$ makes the equation vaniſh; which ſucceeding one of its roots muſt be $-3$. Then dividing the equation by $x + 3$, we find the roots of the (quadratic) quotient

$x^2 - 4x + 2 = 0$ are $2 \pm \sqrt{2}$.

§ 61. If it is required to find the roots of the equation $x^3 - 3x^2 - 46x - 72 = 0$, the operation will be thus:

| *Suppof.* | *Refults* | *Diviſors.* | *Progreſſions.* |
|---|---|---|---|
| $x = 1$ | — 120 | 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 24, 30, 40, 60, 120. | 8 3 4 5 |
| $x = 0$ | — 72 | 1, 2, 3, 4, 6, 8, 9, 12, 18, 24, 36, 72. | 9 2 3 4 |
| $x = -1$ | — 30 | 1, 2, 3, 5, 6, 10, 15, 30. | 10 1 2 3 |

Of theſe four arithmetical progreſſions having their common difference equal to unit, the

| Suppos. | Results | Diviſors. | Progreſſions. |
|---|---|---|---|
| $x=1$ | 120 | 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 24, 30, 40, 60, 120. | |
| $x=0$ | 72 | 1, 2, 3, 4, 6, 8, 9, 12, 18, 24, 36, 72. | 8 3 4 5 |
| $x=-1$ | 30 | 1, 2, 3, 5, 6, 10, 15, 30. | 9 2 3 4 |
| | | | 10 1 2 3 |

r arithmetical progreſſions hav-
ion difference equal to unit, the firſt

4



firſt gives $x=9$, the others give $x=-2$, $x=-3$, $x=-4$; all which ſucceed except $x=-3$: ſo that the three values of $x$ are $+9$, $-2$, $-4$.

## CHAP. VII.

### Of the Reſolution of Equations by finding the equations of a lower degree that are their diviſors.

§ 62. TO find the roots of an equation is the ſame thing as to find the *ſimple* equations, by the multiplication of which into one another it is produced, or to find the ſimple equations that divide it without a remainder.

If ſuch ſimple equations cannot be found, yet if we can find the *quadratic* equations from which the propoſed equation is produced, we may diſcover its roots afterwards by the reſolution of theſe quadratic equations. Or, if neither theſe ſimple equations nor theſe quadratic equations can be found, yet, by finding a *cubic* or *biquadratic* that is a diviſor of the propoſed equation, we may depreſs it lower, and make the ſolution more eaſy.

Now, in order to find the Rules by which theſe diviſors may be diſcovered, we ſhall ſuppoſe that

$$\left.\begin{matrix} mx-n \\ mx^2-nx+r \\ mx^3-nx^2+rx-s \end{matrix}\right\} \text{ are the } \left\{\begin{matrix} \text{ſimple} \\ \text{quadratic} \\ \text{cubic} \end{matrix}\right.$$

diviſors of the propoſed equation; and if $E$ repreſent the quotient ariſing by dividing the propoſed equation by that diviſor, then

$E \times \overline{mx-n}$,

$E \times \overline{mx^2-nx+r}$,

or, $E \times \overline{mx^3-nx^2+rx-s}$, will repreſent the propoſed equation itſelf. Where it is plain, that "ſince $m$ is the coefficient of the higheſt term of the diviſors, it muſt be a diviſor of the coefficient of the higheſt term of the propoſed equation."

§ 63. Next we are to obſerve, that, ſuppoſing the equation has a ſimple diviſor $mx-n$, if we ſubſtitute in the equation $E \times \overline{mx-n}$, in place of $x$, any quantity, as $a$, then the quantity that will reſult from this ſubſtitution will neceſſarily have $ma-n$ for one of its diviſors; ſince, in this ſubſtitution, $mx-n$ becomes $ma-n$.

If we ſubſtitute ſucceſſively for $x$ any arithmetical progreſſion, $a$, $a-a$, $a-2a$, &c. the quantities that will reſult from theſe ſubſtitutions, will have among their diviſors

$ma$

order to find the Rules by wh
rs may be diſcovered, we ſhall ſe

$\left.\begin{matrix} x+r \\ x^2+rx-s \end{matrix}\right\}$ are the $\left\{\begin{matrix} \text{ſimple} \\ \text{quadratic} \\ \text{cubic} \end{matrix}\right.$

the propoſed equation; and t
e quotient ariſing by dividing t
uation by that diviſor, then

$-n,$

$-nx+r,$

$-nx^2+rx-s,$ will repreſent t
uation itſelf. Where it is plai
$m$ is the coefficient of the high
diviſors, it muſt be a diviſ
t of the higheſt term of the p
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in the equation $E \times \overline{mx-n}$,
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nte ſucceſſively for $x$ any ari
ſion, $a$, $a-e$, $a-2e$, &c. the
will reſult from theſe ſubſtitu
among their diviſors



$ma-n,$

$ma-me-n,$

$ma-2me-n,$ which are alſo in arithmetical progreſſion, having their common difference equal to $me$.

If, for example, we ſubſtitute for $x$ the terms of this progreſſion, $1, 0, -1$, the quantities that reſult have among their diviſors the arithmetical progreſſion $m-n, -n, -m-n$; or, changing the ſigns, $n-m, n, n+m$. Where the difference of the terms is $m$, and the term belonging to the ſuppoſition of $x=0$ is $n$.

§ 64. It is manifeſt therefore, that when an equation has any ſimple diviſor, if you ſubſtitute for $x$ the progreſſion $1, 0, -1$, there will be found amongſt the diviſors of the ſums that reſult from theſe ſubſtitutions, one arithmetical progreſſion at leaſt, whoſe common difference will be unit or a diviſor $m$ of the coefficient of the higheſt term, and which will be the coefficient of $x$ in the ſimple diviſor required: and whoſe term, ariſing from the ſuppoſition of $x=0$, will be $n$ the other member of the ſimple diviſor $mx-n$.

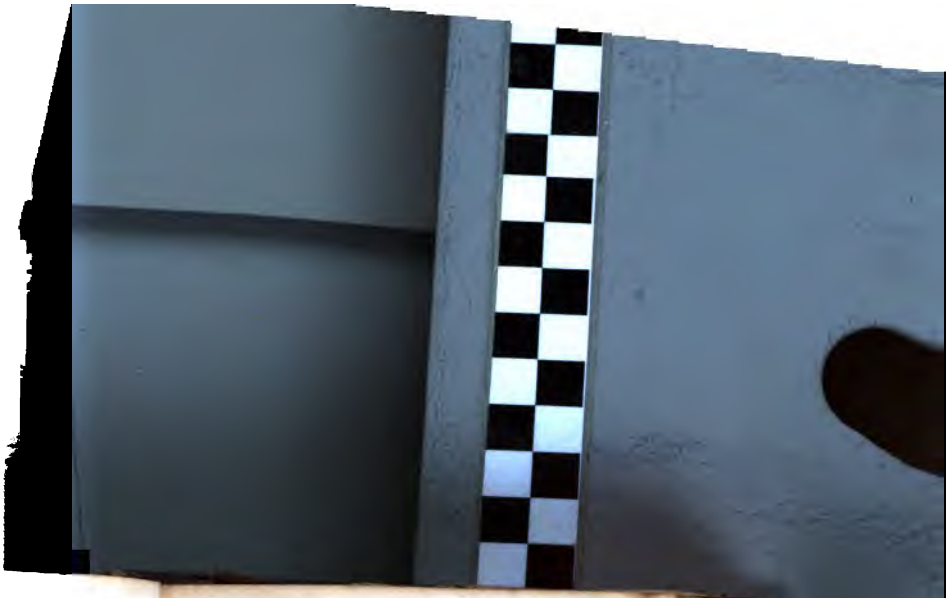
From which this Rule is deduced for diſcovering ſuch a ſimple diviſor, when there is any,

RULE.

" *Subſtitute for* $x$ *in the propoſed equation ſucceſſively the numbers* 1, 0, — 1. *Find all the diviſors of the ſums that reſult from this ſubſtitution, and take out all the arithmetical progreſſions you can find amongſt them, whoſe difference is unit, or ſome diviſor of the coefficient of the higheſt term of the equation. Then ſuppoſe* $n$ *equal to that term of any one progreſſion that ariſes from the ſuppoſition of* $x = 0$, *and* $m =$ *the foreſaid diviſor of the coefficient of the higheſt term of the equation, which* $m$ *is alſo the difference of the terms of this progreſſion; ſo ſhall you have* $mz - n$ *for the diviſor required.*"

You may find arithmetical progreſſions giving diviſors that will not ſucceed; but if there is any diviſor, it will be found thus by means of theſe arithmetical progreſſions.

§ 65. If the equation propoſed has the coefficient of its higheſt term 1, then it will be $m = 1$, and the diviſor will be $x - n$, and the rule will coincide with that given in the end of the laſt chapter, which we demonſtrated after a different manner; for the diviſor being $x - n$, the value of $x$ will be $+ n$, the term of the progreſſion that is a diviſor of the ſum that ariſes from ſuppoſing $x = 0$. Of this caſe we gave





L E.

*the proposed equation fo*
1, 0, — 1. *Find all th*
*s that result from this fo*
*e out all the arithmeti*
*u find amongst them, whi*
*or some divisor of the a*
*ghest term of the equati*
*ual to that term of any o*
*rises from the supposition*
*. the foresaid divisor of th*
*highest term of the equati*
*the difference of the term*
*so shall you have m*
*quired."*

rithmetical progression g
vill not succeed; but if the
ill be found thus by means
progressions.

nation proposed has the coe
heft term 1, then it will b
ivisor will be $x-n$, and the
with that given in the end o
hich we demonstrated after
for the divisor being $x+$
vill be $+n$, the term of the
is a divisor of the sum that
osing $x=0$. Of this case we
gave



gave examples in the last chapter; and though it it easy to reduce an equation whose highest term has a coefficient different from unit, to one where that coefficient shall be unit, by § 30; yet, without that reduction, the equation may be resolved by this rule, as in the following

## EXAMPLE.

§ 66. Suppose $8x^3-26x^2+11x+10=0$, and that it is required to find the values of $x$; the operation is thus:

| *Suppos.* | *Results.* | *Divisors.* | *Progr.* |
|---|---|---|---|
| $x=1$ | $+3$ | 1, 3. | 3 3 |
| $x=0$ | $8x^3-26x^2+11x+10=\begin{cases}+10\\-35\end{cases}$ | 1, 2, 5, 10. | 2 5 |
| $x=-1$ | | 1, 5, 7, 35. | 1 7 |

The difference of the terms of the last arithmetical progression is 2, a divisor of 8, the coefficient of the highest term $x^3$ of the equation, therefore supposing $m=2$, $n=5$, we try the divisor $2x-5$; which succeeding, it follows that $1x-5=0$, or $x=2\frac{1}{2}$.

The quotient is the quadratic $4x^2-3x-2=0$, whose roots are $\frac{3+\sqrt{41}}{8}$, and $\frac{3-\sqrt{41}}{8}$, so that the three roots of the proposed equation are $2\frac{1}{2}$, $\frac{3+\sqrt{41}}{8}$, $\frac{3-\sqrt{41}}{8}$. The other arith-

metical progr
but it does no

§ 67. If the
diviſor, then
ſome quadrati
of more than

An equatio
may be expre
chapter, by
ſtitute for $x$ an
will reſult will
diviſors; and,
$x$ the progreſ
the ſums that
have

$$ma^2 -$$
$$m \times a -$$
$$m \times a -$$
$$m \times a -$$

&c.

amongſt their d

Theſe terms
in arithmetical
tract them fro
$a - \ell$, $a - 2\ell$, $a$
diviſor of the hi
tion, that is fro

ogreſſion gives $x+2$, for a diviſor
not ſucceed.

the propoſed equation has no ſimple
en we are to enquire if it has no
atic diviſor (if itſelf is an equation
n three dimenſions).

ion having the diviſor $mx^2-nx+r$
reſſed as in the firſt article of this
$E \times \overline{mx^2 - nx + r}$; and if we ſup-
any known quantity $a$, the ſum this
ill have $ma^2 - na + r$ for one of its
d, if we ſubſtitute ſucceſſively for
eſſion $a$, $a-e$, $a-2e$, $a-3e$, &c.
t ariſe from this ſubſtitution will

$$\begin{aligned}
&ma^2 - na + r,\\
&m \times \overline{a-e}^2 - n \times \overline{a-e} + r,\\
&m \times \overline{a-2e}^2 - n \times \overline{a-2e} + r,\\
&m \times \overline{a-3e}^2 - n \times \overline{a-3e} + r,
\end{aligned}$$

diviſors, reſpectively.

are not now, as in the laſt caſe,
progreſſion; but if you ſeek
the ſquares of the terms $a$,
$-3e$, &c. multiplied by $m$ t
heſt term of the propoſed equa-

$ma^2$



$$\begin{aligned}
&ma^2,\\
&m \times \overline{a-e}^2,\\
&m \times \overline{a-2e}^2,\\
&m \times \overline{a-3e}^2, \text{ &c. the remainders,}\\
&na - r,\\
&n \times \overline{a-e} - r,\\
&n \times \overline{a-2e} - r,\\
&n \times \overline{a-3e} - r, \text{ &c. ſhall be in arithmetical progreſſion, having their common difference equal to } n \times e.
\end{aligned}$$

If, for example, we ſuppoſe the aſſumed progreſſion $a$, $a-e$, $a-2e$, $a-3e$, &c. to be 2, 1, 0, $-1$, the diviſors will be

$$\left.\begin{aligned} 4m - 2n + r,\\ m - n + r,\\ + r,\\ m + n + r, \end{aligned}\right\} \text{ which ſubtracted from } \left\{\begin{aligned} 4m\\ m\\ 0\\ m \end{aligned}\right\} \text{ reſpectively,}$$

$$\begin{aligned}
\text{leave } & 2n - r,\\
& n - r,\\
& - r,\\
& - n - r,
\end{aligned}$$

an arithmetical progreſſion, whoſe difference is $+n$; and whoſe term ariſing from the ſubſtitution of 0 for $x$ is $-r$.

From which it follows, that by this operation, if the propoſed equation has a quadratic diviſor, you will find an arithmetical progreſſion

ſion that will determine to you $n$ and $r$, the coefficient $m$ being ſuppoſed known; ſince it is unit, or a diviſor of the coefficient of the higheſt term of the equation. Only you are to obſerve, that if the firſt term $mx^2$ of the quadratic diviſor is negative, then in order to obtain an arithmetical progreſſion, you are not to ſubtract, but add the diviſors $-4m-2n+r$, $-m-n+r$, $+r$, $-m+n+r$, to the terms $4m$, $m$, $0$, $m$.

§ 68. The general Rule therefore, deduced from what we have ſaid, is,

" *Subſtitute in the propoſed equation for* $x$ *the terms* 2, 1, 0, $-1$, &c. *ſucceſſively. Find all the diviſors of the ſums that reſult, adding and ſubtracting them from the ſquares of theſe numbers,* 2, 1, 0, $-1$, &c. *multiplied by a numerical diviſor of the higheſt term of the propoſed equation, and take out all the arithmetical progreſſions that can be found amongſt theſe ſums and differences. Let* $r$ *be that term in any progreſſion that ariſes from the ſubſtitution of* $x=0$, *and let* $\mp n$ *be the difference ariſing from ſubtracting that term from the preceding term in the progreſſion; laſtly, let* $m$ *be the foreſaid diviſor of the higheſt term; then ſhall* $mx^2 \pm nx - r$ *be the diviſor that ought to be tried.*" And one or other of the

the divisors found in this manner will succeed, if the proposed equation has a quadratic divisor.

§ 69. Suppose, for example, the biquadratic $x^4 - 5x^3 + 7x^2 - 5x - 6 = 0$ is proposed, which has no simple divisor; then to discover if it has any quadratic divisor, the operation is thus:

Suppos-

| *Suppoſ.* | *Reſults.* | *Diviſors.* | *Squares.* | *Sums and differences of the diviſors and ſquares.* | *Arithmetical Progreſſions.* |
|---|---|---|---|---|---|
| $x=$ 2 | — 12 | 1, 2, 3, 4, 6, 12. | 4 | — 8, —2, 0, 1, 2, 3, 5, 7, 8, 10, 16. | 8 1 —8 3 |
| $x=$ 1 | — 8 | 1, 2, 4, 8. | 1 | — 7, —3, —1, 0, 2, 3, 5, 9. | 5 —1 —7 2 |
| $x=$ 0 | — 6 | 1, 2, 3, 6. | 0 | — 6, —3, —2, —1, 1, 2, 3, 6. | 2 —3 —6 1 |
| $x=-1$ | + 12 | 1, 2, 3, 4, 6, 12. | 1 | — 11, —5, —3, —2, —1, 0, 2, 3, 4, 5, 7, 13. | —1 —5 —5 0 |

The

| Suppos. | Results. | Divisors. | Squares. | Sums and differences of the divisors and squares. | Arithmetical Progressions. |
|---|---|---|---|---|---|
| $x=2$ | $-2$ | 1, 2, 3, 4, 6, 12. | 4 | $-8, -2, 0, 1, 2, 3, 5, 6, 7, 8, 10, 16.$ | 8 1 $-8$ 3 |
| $x=1$ | $8$ | 1, 2, 4, 8. | 1 | $-7, -3, -1, 0, 2, 3, 5, 9.$ | 5 $-1$ $-7$ 2 |
| $x=0$ | $6$ | 1, 2, 3, 6. | 0 | $-6, -3, -2, -1, 1, 2, 3, 6.$ | |
| $x=-1$ | $+12$ | 1, 2, 3, 4, 6, 12. | 1 | | |





The first arithmetical progression gives the divisor $x^2-3x-2$; the second gives $x^2-2x+3$: both which succeed, so that the roots of the two equations $x^2-3x-2=0$, and $x^2-2x+3=0$, *viz.* $\frac{3\pm\sqrt{17}}{2}$ and $1\pm\sqrt{-2}$, are the four roots of the proposed equation, the two last of which are impossible. The divisors which the other arithmetical progressions give, do not succeed.

§ 70. After the same manner a Rule may be discovered for finding the cubic divisors, or those of higher dimensions, of any proposed equation.

Suppose the cubic divisor to be $mx^3-nx^2+rx-s$, and by supposing $x$ equal to the terms of the arithmetical progression, it will be as follows:

| Suppos. | Results. | Cubes of terms of progr. $xm$. | 1st Differ. | 2d Diff. | 3d Diff. |
|---|---|---|---|---|---|
| $x=3$ | $27m-9n+3r-s$ | $27m$ | $9n-3r+s$ | $5n-r$ | $2n$ |
| $x=2$ | $8m-4n+2r-s$ | $8m$ | $4n-2r+s$ | $3n-r$ | $2n$ |
| $x=1$ | $m-n+r-s$ | $m$ | $n-r+s$ | $n-r$ | $2n$ |
| $x=0$ | $-s$ | $0$ | $+s$ | $-n-r$ | |
| $x=-1$ | $-m+n-r-s$ | $-m$ | $n+r+s$ | | |

Where the first differences are not themselves in arithmetical progression, as in the last case, but the differences of its terms, or the second differences, are in arithmetical progression, the common

common difference being $2n$, whence $n$ is known. The quantity $r$ is found in the column of the ſecond difference, and $s$ is always to be aſſumed ſome diviſor of the laſt term of the propoſed equation, as $m$ is of the coefficient of the firſt term. Whence all the coefficients of a diviſor $mx^3 - nx^2 + rx - s$, with which trial is to be made, may be determined.

If it is a diviſor of four dimenſions that is required, by proceeding in like manner, you will obtain a ſeries of differences whoſe ſecond differences are in arithmetical progreſſion. If it is a diviſor of five dimenſions that is required, you will obtain, in the ſame manner, a progreſſion whoſe third differences will be in arithmetical progreſſion; and by obſerving theſe progreſſions, you may diſcover rules for determining the coefficients of the diviſor required.

The foundation of theſe Rules being, that, if an arithmetical progreſſion $a$, $a+e$, $a+2e$, $a+3e$, &c. is aſſumed, the firſt differences of their ſquares will be in arithmetical progreſſion; thoſe differences being $2ae+e^2$, $2ae+3e^2$, $2ae+5e^2$, &c. whoſe common difference is $2e^2$. And the ſecond differences of their cubes, and the third differences of their fourth powers are likewiſe in arithmetical progreſſion, as is eaſily demonſtrated.

§ 71.

§ 71. Hitherto we have only ſhewn how to find the diviſors of equations that involve but *one letter*. But the ſame rules ſerve for diſcovering the diviſors when there are two letters, if all the terms have the ſame dimenſions; for, "*by ſuppoſing one of the letters equal to unit, find the diviſor by the preceding Rules, and then by compleating the dimenſions of the diviſor, ſubſtituting the letter again for unit, you will have the diviſor required.*"

Suppoſe, for example, you are to find the diviſor of $8x^3 - 26ax^2 + 11a^2x + 10a^3 = 0$, by putting $a = 1$, that quantity becomes $8x^3 - 26x^2 + 11x + 10 = 0$; whoſe diviſor was found, § 66. to be $2x - 5$; now multiply the term $-5$ by $+a$, to bring it to the ſame dimenſions as the other, and the diviſor required is $2x - 5a$.

§ 72. Beſides the method hitherto explained for finding the diviſors of lower dimenſions that may divide the propoſed equation, there are others that deſerve to be conſidered. The following is applicable to equations of all ſorts, though we give it only for thoſe of four dimenſions.

Let the biquadratic $x^4 - px^3 + qx^2 - rx + s = 0$ be the equation propoſed; and let us ſuppoſe it is the product of theſe two quadratic equations,

$x^2$

$$x^2 - mx + n = 0$$
$$\times\, x^2 - kx + l = 0$$

$$x^4 - \left.\begin{matrix} k \\ m \end{matrix}\right\} x^3 + \left.\begin{matrix} l \\ n \\ mk \end{matrix}\right\} x^2 - \left.\begin{matrix} ml \\ nk \end{matrix}\right\} x + ln = 0,$$

the terms of which will be equal, reſpectively, to the terms of the propoſed equation.

In this equation, $l$ and $n$ being diviſors of the laſt term $s$, we may conſider one of them (*viz.* $l$) as known; and in order to find $m$ or $k$, we need only compare the terms of this equation with the terms of the propoſed equation reſpectively, which gives,

1°. $k + m = p$.
2°. $mk + l + n = q$.
3°. $ml + nk = r$.
4°. $nl = s$.

Now in order to find an equation that ſhall involve only $k$, and known terms, take the two values of $m$ that ariſe from the firſt and third equations, and you will find,

$m = p - k = \frac{r - nk}{l}$ (becauſe $n = \frac{s}{l}$, by equation the fourth) $= \frac{r - \frac{ks}{l}}{l} = \frac{rl - ks}{l^2}$; whence $pl^2 - kl^2 = rl - ks$, and $k = \frac{pl^2 - rl}{l^2 - s}$; and the quadratic $x^2 - kx + l = 0$ becomes $x^2 - \frac{pl^2 - rl}{l^2 - s} \times x + l = 0$.

To

To apply this to practice, you muſt ſubſtitute ſucceſſively for $l$ all the diviſors of $s$, the laſt term of the propoſed equation, till you find one of them ſuch, that $x^2 - \frac{pl^2 - rl}{l^2 - s} \times x + l$ can divide the propoſed equation without a remainder.

## EXAMPLE

§ 73. If the equation $x^4 - 6x^3 + 20x^2 - 34x + 35 = 0$ is propoſed. The diviſors of 35 are 1, 5, 7, 35; if you put $l = 1$, the quadratic that ariſes will not ſucceed. But if you ſuppoſe $l = 5$, then the equation $x^2 - kx + l$, that is $x^2 - \frac{pl^2 - rl}{l^2 - s} \times x + l = 0$ becomes

$$x^2 - \frac{6 \times 25 - 34 \times 5}{25 - 35} x + 5 = 0 = x^2 - 2x + 5,$$

which divides the propoſed equation without a remainder, and gives the quotient $x^2 - 4x + 7 = 0$.

"In this operation it is unneceſſary to try any diviſor $l$, that exceeds the ſquare root of $s$, the laſt term of the propoſed equation." And, if the propoſed equation is literal, "you need only try thoſe diviſors of the laſt term that are of two dimenſions."

If, in any ſuppoſition of $l$, the value of $k$, viz. $\frac{pl^2 - rl}{l^2 - s}$, becomes a fraction, then that ſuppoſition is to be rejected, and another value of $l$ to be tried.

§ 74. By comparing the ſecond and fourth equations of the laſt article, you may obtain another value of $k$. For $n = q - l - mk = \frac{s}{l}$; ſo that ($m$ being equal to $p - k$) $\frac{s}{l} = q - l - pk + k^2$, and $k^2 - pk + q - l - \frac{s}{l} = 0$. Which gives $k = \frac{1}{2}p \pm \sqrt{\frac{1}{4}p^2 - q + l + \frac{s}{l}}$. So that the quadratic diviſor required becomes

$$x^2 - \tfrac{1}{2}p \mp \sqrt{\tfrac{1}{4}p^2 - q + l + \tfrac{s}{l}} \times x + l = 0.$$

This diviſor muſt be tried when $l = \frac{s}{l}$, and at the ſame time $l = \frac{r}{p}$, the former expreſſion not ſerving in that caſe.

By this formula, diviſors may be found whoſe ſecond terms may be *irrational*.

How the diviſors of higher equations may be found, when they have any, may be underſtood from what has been ſaid of thoſe of four dimenſions.

SUPPLE-

## SUPPLEMENT to CHAP. VII.

## Of the Reduction of Equations by Surd diviſors.

AN equation of four, ſix, or more dimenſions, although it may admit of no rational diviſor, may have one that is irrational. As the biquadratic $x^4 + px^3 + qx^2 + rx + s = 0$, which we ſuppoſe to be irreducible by any rational diviſor, may yet, by adding a ſquare $k^2x^2 + 2klx + l^2$ multiplied into ſome quantity $n$, be compleated into a ſquare $\overline{x^2 + \frac{1}{2}px + \mathcal{Q}}^2$. In which caſe we ſhall have $x^2 + \frac{1}{2}p + \mathcal{Q} = \sqrt{n} \times \overline{kx + l}$, and $x$ is found by the reſolution of an affected quadratic equation.

To reduce a biquadratic equation in this manner, we have the following

### RULE.

* If the biquadratic is $x^4 + px^3 + qx^2 + rx + s = 0$, where $p$, $q$, $r$, $s$, repreſent the given coefficients under their proper ſigns, *put* $q - \frac{1}{4}p^2 = \alpha$, $r - \frac{1}{2}\alpha p = \beta$, $s - \frac{1}{4}\alpha^2 = \zeta$. And for $n$ *take ſome integer common diviſor of* $\beta$ *and* $2\zeta$, *that is not a ſquare number, and which, if either* $p$ *or* $r$ *is an odd number, muſt be odd, and, di-*

* *Arithmet. Univerſ.* pag. 264.

*vided by* 4, *leave the remainder unity. Write likewiſe for* $k$ *ſome diviſor of* $\frac{\beta}{n}$ *if* $p$ *is an even number, or the half of an odd diviſor if* $p$ *is odd, or* 0 *if* $\beta = 0$. *Subtract* $\frac{\beta}{nk}$ *from* $\frac{1}{2}pk$, *and let the remainder be* $l$. *For* $\mathcal{Q}$ *put* $\frac{\alpha + nk^2}{2}$, *and try if, dividing* $\mathcal{Q}^2 - s$ *by* $n$, *the root of the quotient is rational and equal to* $l$; *if it is, add* $nk^2x^2 + 2nklx + nl^2$ *to both ſides of the equation, and extracting the root you ſhall have* $x^2 + \frac{1}{2}px + \mathcal{Q} = n^{\frac{1}{2}} \times \overline{kx + l}$.

## EXAMPLE I.

Let the equation propoſed be $x^4 + 12x - 17 = 0$, and becauſe $p = 0$, $q = 0$, $r = 12$, $s = -17$, we ſhall have $\alpha = 0$, $\beta = 12$, $\zeta = -17$. And $\beta$ and $2\zeta$, that is 12 and $-34$, having only 2 for a common diviſor, it muſt be $n = 2$. Again, $\frac{\beta}{n} = 6$, whoſe diviſors 1, 2, 3, 6, are to be ſucceſſively put for $k$, and $-3$, $-\frac{3}{2}$, $-1$, $-\frac{1}{2}$ for $l$ reſpectively.

But $\frac{\alpha + nk^2}{2}$, that is $k^2$, is equal to $\mathcal{Q}$, and $\sqrt{\frac{\mathcal{Q}^2 - s}{n}} = l$. And when the even diviſors 2 and 6 are ſubſtituted for $k$, $\mathcal{Q}$ becomes 4 and 36, and

and $\mathfrak{Q}^2 - s$ being an odd number, is not divisible by $n(=2)$. Wherefore 2 and 6 are to be set aside. But when 1 and 3 are written for $k$, $\mathfrak{Q}$ is 1 or 9, and $\mathfrak{Q}^2 - s$ is 18 or 98 respectively; which numbers can be divided by 2, and the roots of the quotients extracted, being $\pm 3$ and $\pm 7$; but only one of them, *viz.* $-3$, coincides with $l$. I put therefore $k = 1$, $l = -3$, $\mathfrak{Q} = 1$, and adding to both sides of the equation $nk^2x^2 + 2nklx + nl^2$, that is, $2x^2 - 12x + 18$, there results $x^4 + 2x^2 + 1 = 2x^2 - 12x + 18$, and extracting the root of each, $x^2 + 1 = \pm\sqrt{2} \times \overline{x-3}$. And again, extracting the root of this last, the four values of $x$, according to the varieties in the signs, are

$$-\tfrac{1}{2}\sqrt{2} + \sqrt{3\sqrt{2} - \tfrac{1}{2}},\ -\tfrac{1}{2}\sqrt{2} - \sqrt{3\sqrt{2} - \tfrac{1}{2}};$$

$$\tfrac{1}{2}\sqrt{2} + \sqrt{-3\sqrt{2} - \tfrac{1}{2}},\ \tfrac{1}{2}\sqrt{2} - \sqrt{-3\sqrt{2} - \tfrac{1}{2}},$$

being the roots of $x^4 + 12x - 17 = 0$, the equation at first proposed.

## EXAMPLE II.

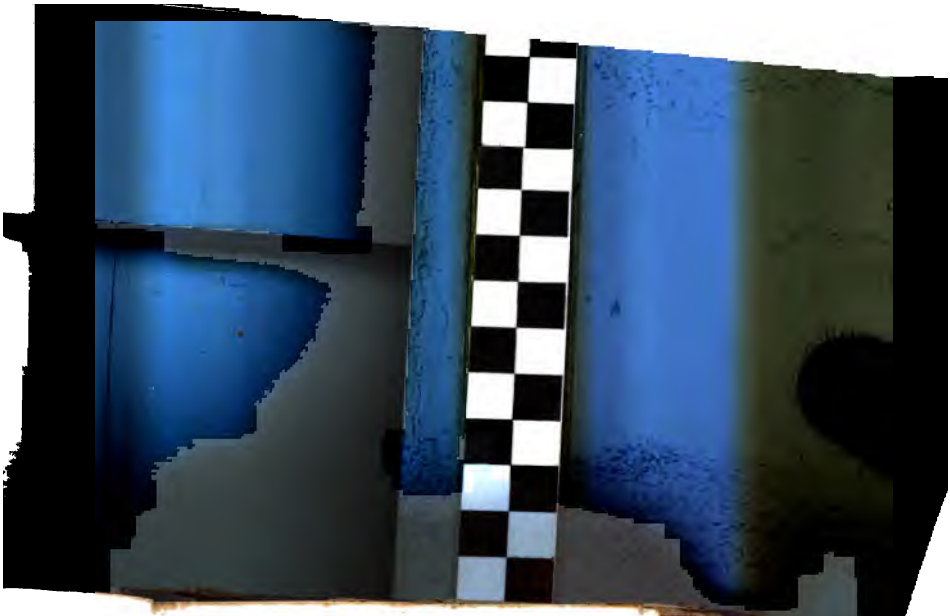
Let the equation be $x^4 - 6x^3 - 58x^2 - 114x - 11 = 0$. and writing $-6$, $-58$, $-114$, $-11$ for $p$, $q$, $r$, $s$, respectively, we have $-67 = \alpha$, $-315 = \beta$, and $-1133\frac{1}{2} = \zeta$. The numbers $\beta$ and $2\zeta$, that is $-315$ and $-\frac{4533}{2}$, have but one common divisor 3, that is $n = 3$. And the

divisors of $-105=\frac{\beta}{n}$ are 3, 5, 7, 15, 21, 35, and 105. Wherefore I first make trial with $3=k$, and dividing $\frac{\beta}{n}$ or $-105$, by it get the quotient $-35$, and this subtracted from $\frac{1}{2}pk=-3\times 3$, leaves 26, whose half, 13, ought be equal to $l$. But $\frac{\alpha+nk^2}{2}$, or $\frac{-67+27}{2}$, that is, $-20$ is equal to $\mathfrak{Q}$; and $\mathfrak{Q}^2-s=411$, which is indeed divisible by $n=3$; but the root of the quotient 137 cannot be extracted. Therefore I reject the divisor 3, and try with $5=k$; by which dividing $\frac{\beta}{n}=-105$, the quotient is $-21$, and this taken from $\frac{1}{2}pk=-3\times 5$, leaves $6=2l$. At the same time, $\mathfrak{Q}\left(=\frac{\alpha+nk^2}{2}\right)=-\frac{75+67}{2}=4$. And $\mathfrak{Q}^2-s$, or $16+11$, is divisible by $n$, and the root of the quotient 9, that is, 3, coincides with $l$. Whence I conclude that putting $l=3$, $k=5$, $\mathfrak{Q}=4$, $n=3$, adding to both sides of the equation the quantity $nk^2x^2+2nklx+nl^2$, that is, $75x^2+90x+27$, and extracting the roots, it will be

$$x^2+\tfrac{1}{2}px+\mathfrak{Q}=\sqrt{n}\times\overline{kx+l}, \text{ or}$$
$$x^2-3x+4=\pm\sqrt{3}\times\overline{5x+3}.$$

## EXAMPLE. III.

In like manner in the equation $x^4-9x^3+15x^2+27x+9=0$ writing $-9, +15, -27, +9$, for





for $p, q, r, s$, there result $\alpha = -5\frac{1}{4}, -50\frac{1}{8} = \beta$, $2\frac{7}{64} = \zeta$. The common divisors of $\beta$ and $2\zeta$, that is, of $\frac{405}{8}$ and $\frac{135}{32}$ are 3, 5, 9, 15, 27, 45, 135; but 9 is a square, and 3, 15, 27, 135 divided by 4 do not leave unity for a remainder, as is required when $p$ is an odd number. Setting these aside there remain only 5 and 45 to be tried for $n$. First let $n = 5$, and the halves of the odd divisors of $\frac{\beta}{n} = -\frac{81}{8}$, that is, $\frac{1}{2}$, $\frac{3}{2}$, $\frac{9}{2}$, $\frac{27}{2}$, $\frac{81}{2}$, are to be tried for $k$. If $k = \frac{1}{2}$, the quotient $-\frac{81}{4}$ of $\frac{\beta}{n}$ divided by $k$, taken from $\frac{1}{2}pk$ or $-\frac{9}{4}$, leaves $18 = 2l$: and $\mathcal{Q}\left(= \frac{\alpha + nk^2}{2}\right) = -2$, $\mathcal{Q}^2 - s = -5$, which is divisible by 5, but the root of the quotient $-1$, which should be $l = 9$, is imaginary. Put next $k = \frac{3}{2}$, and the quotient of $\frac{\beta}{n}$ divided by $k$, or of $-\frac{81}{8}$ by $\frac{3}{2}$, is $-\frac{27}{4}$. This subtracted from $\frac{1}{2}pk = -\frac{27}{4}$, leaves nothing, that is $l = 0$. Again, $\mathcal{Q}\left(= \frac{\alpha + nk^2}{2}\right) = 3$, and $\mathcal{Q}^2 - s = 0$, and $l\left(= \sqrt{\frac{\mathcal{Q}^2 - s}{n}}\right) = 0$. From which coincidence I infer that $n = 5$, $k = \frac{3}{2}$, $l = 0$, and adding $nk^2x^2 + 2nlkx + nl^2$, that is, $\frac{45}{4}x^2$ to both sides of the equation, I find $x^2 - 4\frac{1}{2}x + 3 = \sqrt{5} \times \frac{1}{2}x$.

*Literal* equations may be treated much in the ſame way. And, if you put $n=1$, the ſame Rule will give you the *rational* diviſor of a biquadratic equation, if it admits of one. Thus for the equation $x^4-x^3+5x^2+12x-6=0$, putting $n=1$ I find $k=\frac{5}{2}$, $l=-\frac{5}{2}$, and the equation is reduced to the two quadratics $x^2-3x+3=0$ and $x^2+2x-2=0$.

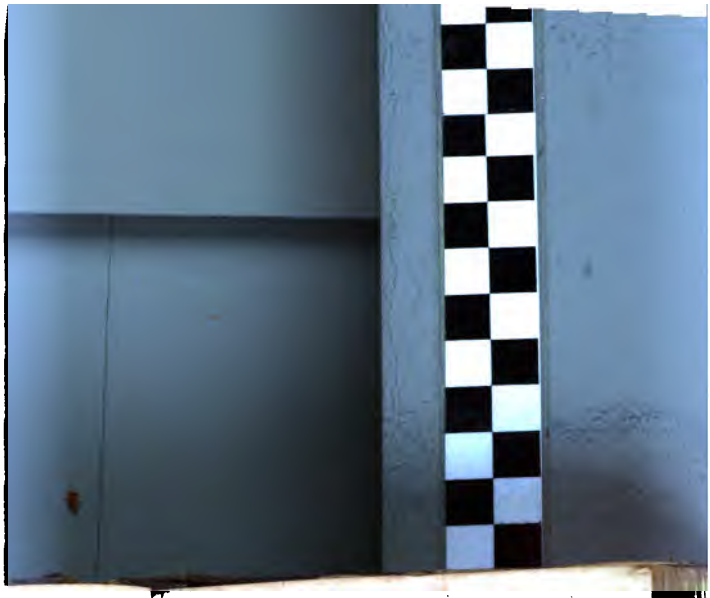
When the diviſors of $\frac{\beta}{n}$ are ſo many that it would be troubleſome to make trial with them all for $k$, their number may be reduced by finding all the diviſors of $\alpha s-\frac{1}{4}r^2$. For to one of theſe, or to its half when odd, the number $Q$ muſt be equal.

The ground of this Rule is as follows.

If a biquadratic equation $x^4+px^3+qx^2+rx+s=0$, in which $p$, $q$, $r$, $s$, are the given coefficients with their ſigns, and the equation is ſuppoſed clear of fractions and ſurds; if this equation can be compleated into a ſquare, in the manner already deſcribed, we ſhall have $x^4+px^3+qx^2+rx+s+nk^2x^2+2nklx+nl^2=nk^2x^2+2nklx+nl^2=\overline{x^2+\frac{1}{2}px+Q}^2$, that is, $x^4+px^3+\overline{q+nk^2}\times x^2+\overline{r+2nkl}\times x+s+nl=x^4+px^3+\overline{2Q+\frac{1}{4}p^2}\times x^2+pQ\times x+Q^2$. And comparing the terms, we get theſe *three* equations,

1. $q+nk^2=2Q+\frac{1}{4}p^2$,

2.





may be treated much
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if it admits of one. The
$x^3+5x^2+12x-0=0$,
$k=\frac{5}{2}$, $l=-\frac{5}{2}$, an
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is as follows.
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we shall have
$-2nklx+n^2l^2=$
$\mathfrak{Q})^2$, that is,
$\times x+s+nl$
$\mathfrak{Q}\times x+\mathfrak{Q}^2$.
these three

2.



2. $r+2nkl=p\mathfrak{Q}$,
3. $s+nl^2=\mathfrak{Q}^2$;

in which there being four unknown quantities, they can be found only by trial.

The values of $\mathfrak{Q}$, taken from the firſt and ſecond equations and made equal to each other, give $n=\frac{\frac{1}{2}pq-\frac{1}{8}p^3-r}{2kl-\frac{1}{2}pk^2}$ (writing, as in the Rule, $q-\frac{1}{4}p^2=\alpha$, and $r-\frac{1}{2}\alpha p=\beta$) $=\frac{\beta}{k\times\overline{\frac{1}{2}pk-2l}}$. Whence, if the quantities $n$, $k$, $l$, $\mathfrak{Q}$, are to be found, it follows, (1°.) That $n$ being a diviſor of $\beta$, giving the quote $k\times\overline{\frac{1}{2}pk-2l}$, $k$ will be a diviſor of $\frac{\beta}{n}$, giving the quote $\frac{1}{2}pk-2l$; and that ſubtracting this quote from $\frac{1}{2}pk$, $l$ will be equal to half the remainder. (2°.) In the firſt equation we had $\mathfrak{Q}=\frac{\alpha+nk^2}{2}$, and, from the third, $l^2=\frac{\mathfrak{Q}^2-s}{n}$. (3°.) Becauſe $\mathfrak{Q}=\frac{1}{2}\alpha+\frac{1}{2}nk^2$ and $nl^2=\mathfrak{Q}^2-s$, $n=\frac{\frac{1}{4}\alpha^2-s}{l^2-\frac{1}{2}\alpha k^2-\frac{1}{4}nk^4}=\frac{2s-\frac{1}{2}\alpha^2}{k^2\times\alpha+\frac{1}{2}nk^2-2l^2}$ (if $\zeta=s-\frac{1}{4}\alpha^2$) $=\frac{2\zeta}{k^2\times\alpha+\frac{1}{2}nk^2-2l^2}$, that is, $n$ divides $2\zeta$ by $k^2\times\overline{\alpha+\frac{1}{2}nk^2}-l^2$. And if the ſeveral values of the quantities $n$, $k$, $l$, $\mathfrak{Q}$, anſwer to thoſe conditions, or coincide, it is a proof that they have been rightly aſſumed; and that adding to the given equation the quantity $n\times\overline{kx+l}^2$, it will be compleated into the ſquare $\overline{x^2+\frac{1}{2}p+\mathfrak{Q}}^2$.

It

It was ſaid that $\mathcal{Q}$ will always be ſome diviſor of $\alpha s - \frac{1}{4}r^2$. For $\alpha s = \alpha\mathcal{Q}^2 - \alpha nl^2$, and taking from both $\frac{1}{4}r^2 = \frac{1}{4}p^2\mathcal{Q}^2 - p\mathcal{Q}nkl + n^2k^2l^2$, ſeeing the remainder $\alpha\mathcal{Q}^2 - \alpha + nk^2 \times nl^2 - \frac{1}{4}p^2\mathcal{Q}^2 + p\mathcal{Q}nkl = \alpha\mathcal{Q}^2 - 2\mathcal{Q} \times nl^2 - \frac{1}{4}p^2\mathcal{Q}^2 + p\mathcal{Q}nkl$, has $\mathcal{Q}$ in every term; the thing is manifeſt.

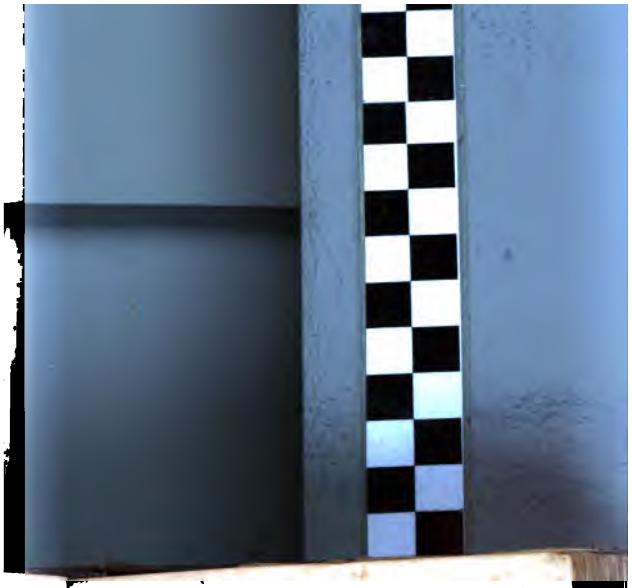
It is needleſs to be particular as to the ſeveral limitations in the Rule, ſeeing they follow eaſily from the algebraical expreſſions of the quantities. You are not, for inſtance, if you ſeek a ſurd diviſor, to take $n$ a ſquare number, for if $n$ is a ſquare number, $\sqrt{n} \times \overline{kx + l}$ would be rational. Or if $n$ is a multiple of a ſquare, as $\nu \times m^2$, then, at leaſt, $m \times \overline{kx + l}$ would be rational, and $n$ would be depreſſed to $\nu$.

Let us examine one caſe, *when p is even and r odd*; and by the Rule $n$ muſt be an odd number, a multiple of 4 more unity.

1. Seeing $\beta = r - \frac{1}{2}\alpha p$, or $\beta + \frac{1}{2}\alpha p = r$, of the numbers $\beta$ and $\frac{1}{2}\alpha p$ one muſt be even and the other odd, that their ſum $r$ may be odd. If $\beta$ is odd, its diviſor $n$ muſt be odd likewiſe. Suppoſe $\beta$ to be even, then $\frac{1}{2}\alpha p$, and conſequently $\frac{1}{2}p$ and $\alpha$ are both odd. But if $\alpha$ is odd, $2\zeta = 2s - \frac{1}{2}\alpha^2$ will be half an odd number, and $n$ its diviſor is odd.

In this caſe, $\mathcal{Q}$ is half an odd number. For let it be an integer, $p\mathcal{Q}$ will be an even number. But if $\mathcal{Q}$ is an integer, ſo muſt $l$, becauſe

$s +$





$s + n^2 = \mathcal{Q}^2$; and $2nkl$ muſt be even. And $r + 2nkl$ (an odd number) $= p\mathcal{Q}$ an even number, *which is abſurd.*

2. Let $N$ repreſent any number in general, $I$ an odd number; then I ſay, "every odd number is a multiple of *four*, more or leſs *unity*," that is, $I = 4N \pm 1$. "The ſquare of an odd number is $4N + 1$," (that is ſome multiple of 4, more unity;) and "if from ſuch a ſquare there be taken any multiple of 4, the remainder, if greater than unity, will be $4N + 1$."

Hence it follows that $n = 4N + 1$. For ſeeing $n^2 = \mathcal{Q}^2 - s$; becauſe $l$ and $\mathcal{Q}$ are the halves of odd numbers, we have, according to the preſent notation, $\frac{n \times I^2}{4} = \frac{I^2 - 4s}{4}$, or without the common denominator $n \times I^2 = I^2 - 4s$, that is, $n \times \overline{4N + 1} = 4N + 1$, and conſequently $n = 4N + 1$. For it is not $4N - 1$ but $4N + 1$ that can give the product $4N + 1$. *

In

* In the former Editions, there were here inſerted two Rules for the Caſe of $\beta = 0$: which, tho' true, Mr. *Thomas Simpſon* has, in his *Miſcellaneous Tracts*, publiſhed 1757, ſhewn to be unneceſſary. In *this*, therefore, they are omitted.

It is only to be regretted that Mr. *Simpſon* ſhould, through inattention, have placed this inaccuracy, not to the account of the Editor, as he ought to have done, but to that of Mr. MACLAURIN. The whole explanation of Sir *Iſaac*'s Method of Reducing Equations by means of *Surd Diviſors*, is (pag. 223.) profeſſedly a *Supplement*; as is likewiſe the Addition to *Chap.* 14. *Part.* 1. And the Edi-

In like manner the other limitations may be determined: and what has been ſaid may lead to the invention or demonſtration of ſimilar Rules for the higher equations of even dimenſions, if any one pleaſes to take the trouble.

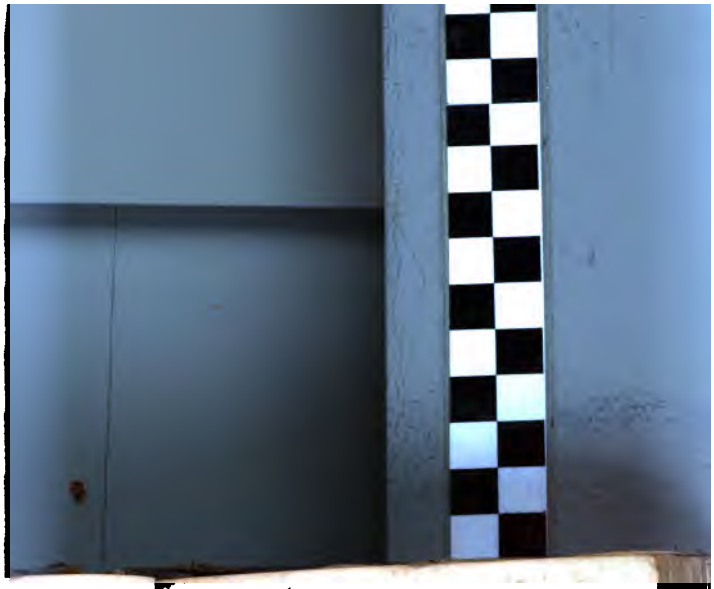
## CHAP. VIII.

### Of the Reſolution of Equations by *Cardan*'s Rule, and others of that kind.

§ 75. WE now proceed to ſhew how an expreſſion of the root of an equation can be obtained that ſhall involve only known quantities. In *Chapter* 11. *Part*. I. we ſhewed how to reſolve *ſimple* equations; and in *Chapter* 13. we ſhewed how to reſolve any *quadratic* equation, by adding to the ſide of the equation that involves the unknown quantity, what was neceſſary to make it a compleat ſquare, and then extracting the ſquare root on both ſides. In § 27 of this *Part*, we gave another method

Editor thought he had, in his Preface, ſufficiently intimated that a few ſuch inſertions had been made, and the reaſon why: tho' he cannot recollect any others worth mentioning; if it is not §§ 123, 124, of *Part* II.

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of reſolving *quadratic* equations, by taking away the ſecond term: where it appeared that if $x^2-px+q=0$, $x=\frac{1}{2}p\pm\sqrt{\frac{1}{4}p^2-q}$.

§ 76. The ſecond term can be taken away out of any *cubic* equation, by § 25; ſo that they all may be reduced to this form, $x^3+qx+r=0$.

Let us ſuppoſe that $x=a+b$; and $x^3+qx+r=a^3+3a^2b+3ab^2+b^3+qx+r=a^3+3ab\times\overline{a+b}+b^3+qx+r=a^3+3abx+b^3+qx+r$ (by ſuppoſing $3ab=-q$) $=a^3+b^3+r=0$.

But $b=-\frac{q}{3a}$, and $b^3=-\frac{q^3}{27a^3}$, and conſequently, $a^3-\frac{q^3}{27a^3}+r=0$; or, $a^6+ra^3+\frac{q^3}{27}$.

Suppoſe $a^3=z$, and you have $z^2+rz=\frac{q^3}{27}$; which is a quadratic whoſe reſolution gives

$$z=-\tfrac{1}{2}r\pm\sqrt{\tfrac{1}{4}r^2+\tfrac{q^3}{27}}=a^3,$$

and $a=\sqrt[3]{-\frac{1}{2}r\pm\sqrt{\frac{1}{4}r^2+\frac{q^3}{27}}}$; and

$$x=a+b=a-\frac{q}{3a}=\sqrt[3]{-\tfrac{1}{2}r\pm\sqrt{\tfrac{1}{4}r^2+\tfrac{q^3}{27}}}-\frac{q}{3\sqrt[3]{-\frac{1}{2}r\pm\sqrt{\frac{1}{4}r^2+\frac{q^3}{27}}}}$$

: in which expreſſions there are only known quantities.

§ 77.

§ 77. The values of $x$ may be found a little differently, thus:

Since $a^3 = -\frac{1}{2}r \pm \sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}$, it follows, that $a^3 + r = +\frac{1}{2}r \pm \sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}$, and $b^3 (= -a^3 - r) = -\frac{1}{2}r \mp \sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}$; so that $b = \sqrt[3]{-\frac{1}{2}r \mp \sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}}$; and $x (= a + b) = \sqrt[3]{-\frac{1}{2}r \pm \sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}} + \sqrt[3]{-\frac{1}{2}r \mp \sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}}$; which gives but one value of $x$, becauſe when, in the value of $a$ the ſurd $\sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}$ is poſitive, it is negative in the value of $b$, and there is only the difference of this ſign in their values. So that we may conclude

$$x = \sqrt[3]{-\frac{1}{2}r + \sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}} + \sqrt[3]{-\frac{1}{2}r - \sqrt{\frac{1}{4}r^2 + \frac{q^3}{27}}}.$$

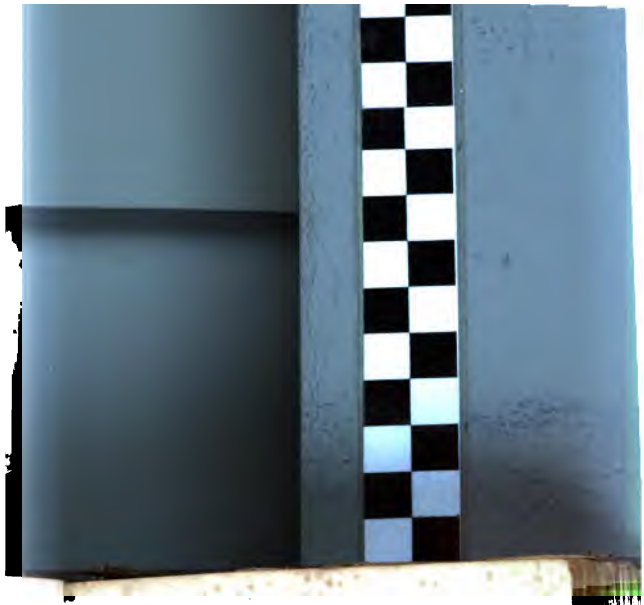
§ 79. * The values of $x$ may be diſcovered without exterminating the ſecond term.

Any cubic equation may be reduced to this form,

$$\left.\begin{matrix} x^3 - 3px^2 - 3px - 2r \\ + 3p^2x - p^3 \\ + 3pq \end{matrix}\right\} = 0,$$

* Vid. Phil. Tranſ. 309.

which





which, by ſuppoſing $x = z + p$, will be reduced to $z^3 - 3qz - 2r = 0$, in which the ſecond term is wanting. But by the laſt article, ſince $z^3 - 3qz - 2r = 0$, it follows that

$z = \sqrt[3]{r + \sqrt{r^2 - q^3}} + \sqrt[3]{r - \sqrt{r^2 - q^3}}$ (if you ſuppoſe that the cubic root of the binomial $r + \sqrt{r^2 - q^3}$ is $m + \sqrt{n}$) $= m + \sqrt{n} + m - \sqrt{n} = 2m$. And ſince $x = z + p$, it follows that $x = p + 2m$.

§ 79. But as the ſquare root of any quantity is *twofold*, "the cube root is *threefold*," and can be expreſſed three different ways.

Suppoſe the cube root of unit is required, and let $y^3 = 1$, or $y^3 - 1 = 0$, then ſince unit itſelf is a cube root of 1, one of the values of $y$ is 1, ſo that the equation $y - 1 = 0$ ſhall divide the firſt equation $y^3 - 1 = 0$, and the quotient $y^2 + y + 1 = 0$ reſolved, gives $y = \frac{-1 \mp \sqrt{-3}}{2}$; ſo that the three expreſſions of $\sqrt[3]{1}$ are, $\frac{-1 + \sqrt{-3}}{2}$, and $\frac{-1 - \sqrt{-3}}{2}$. And, in general, the cube root of any quantity $A^3$ may be $A$, or $\frac{-1 + \sqrt{-3}}{2} \times A$, or $\frac{-1 - \sqrt{-3}}{2} \times A$; ſo that the cube root of the binomial $r + \sqrt{r^2 - q^3}$ may be $m + \sqrt[3]{n}$, as we ſuppoſed above, or $\frac{-1 + \sqrt{-3}}{2} \times m$

$\times \sqrt[2]{m+\sqrt{n}}$, or $\frac{-1-\sqrt{-3}}{2} \times \sqrt[2]{m+\sqrt{n}}$. And hence we have three expreſſions for $x$, *viz.*

1°. $x = p \times 2m$,

2°. $x = p - m + \sqrt{-3n}$,

3°. $x = p - m - \sqrt{-3n}$;

and theſe give the three roots of the propoſed cubic equation.

## EXAMPLE I.

§ 80. Let it be required to find the roots of the equation $x^3 - 12x^2 + 41x - 42 = 0$.

Comparing the coefficients of this equation with thoſe of the general equation

$$\left.\begin{matrix} x^3 - 3px^2 - 3q \\ +3p^2 \end{matrix}\right\} x \left.\begin{matrix} -2r \\ -p^3 \\ +3pq \end{matrix}\right\} = 0,$$ you find,

1°. $3p = 12$, ſo that . . . . . $p = 4$,

2°. $3p^2 - 3q\ (= 48 - 3q) = 41$ . . . $q = \frac{7}{3}$,

3°. $3pq - p^3 - 2r\ (= -36 - 2r) = -42$ . . $r = 3$;

and conſequently, $r^2 - q^3 = 9 - \frac{343}{27} = -\frac{100}{27}$,

and $r + \sqrt{r^2 - q^3} = 3 + \sqrt{-\frac{100}{27}}$. Now the cube root of this binomial is found to be $-1 + \sqrt{-\frac{4}{3}}\ (= m + \sqrt{n})$*. Whence,

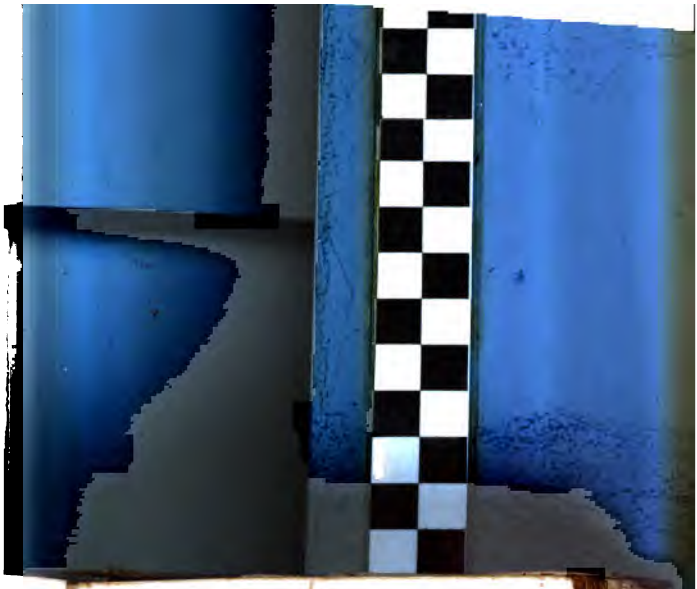
1°. $x = p + 2m = 4 - 2 = 2$.

2°. $x = p - m - \sqrt{-3n} = 4 + 1 - \sqrt{4} = 5 - 2 = 3$.

3°. $x = p - m + \sqrt{-3n} = 5 + 2 = 7$.

* Section 131. Part I.

So





So that the three roots of the propoſed equation are 2, 3, 7.

You may find other two expreſſions of the cube root of $3+\sqrt{-\frac{100}{27}}$, beſides $-1+\sqrt{-\frac{4}{3}}$, viz. $\frac{3}{2}+\sqrt{-\frac{1}{12}}$, and $-\frac{1}{2}-\sqrt{-\frac{25}{12}}$; but theſe ſubſtituted for $m+\sqrt{n}$ give the ſame values for $x$, as are already found.

## EXAMPLE II.

In the equation $x^3+15x^2+84x-100=0$, you find $p=-5$, $q=-3$, $r=135$, and $r+\sqrt{r^2-q^3}=135+\sqrt{18252}$, whoſe cube root is $3+\sqrt{12}$; ſo that $x\,(=p+2m)=-5+6=1$. The other two values of $x$, viz. $-8+\sqrt{-36}$, $-8-\sqrt{-36}$, are impoſſible.

After the ſame manner, you will find that the roots of the equation $x^3+x^2-166x+660=0$, are $-15, 7\pm\sqrt{5}$. The Rule by which we may diſcover if any of the roots of an equation are *impoſſible*, ſhall be demonſtrated afterwards.

§ 82. The roots of biquadratic equations may be found by reducing them to cubes, thus.

Let the ſecond term be taken away by the Rule given in *Chap.* 3. And let the equation that reſults be

$$x^4+qx^2+rx+s=0.$$

And let us ſuppoſe this biquadratic to be the product of theſe two quadratic equations,

$$x^2 + ex + f = 0$$
$$x^2 - ex + g = 0$$

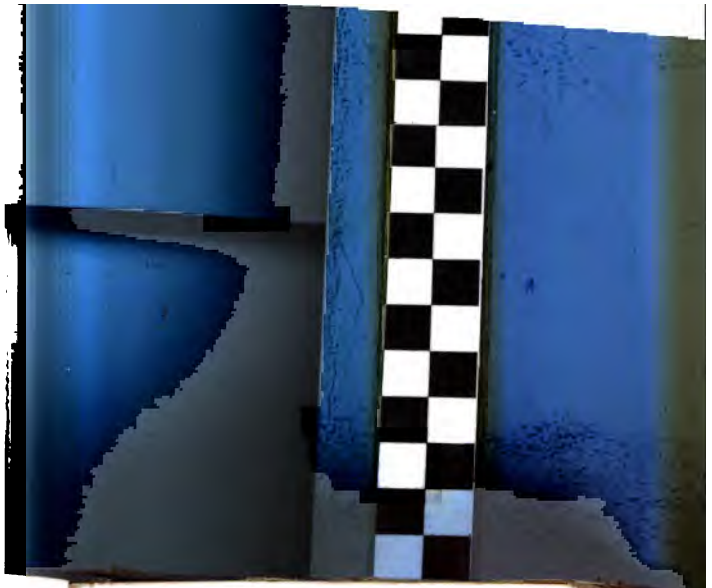
$$x^{4\&} \left\{ \begin{matrix} +f \\ +g \\ -e^2 \end{matrix} \right\} \times x^2 \left\{ \begin{matrix} +eg \\ -ef \end{matrix} \right\} \times x + fg = 0.$$

Where $e$ is the coefficient of $x$ in both equations but affected with contrary signs; becauſe when the ſecond term is wanting in an equation, the ſum of the affirmative roots muſt be equal to the ſum of the negative.

Compare now the propoſed equation with the above product, and the reſpective terms put equal to each other will give $f + g - e^2 = q$, $eg - ef = r$, $fg = s$. Whence it follows, that $f + g = q + e^2$, and $g - f = \frac{r}{e}$; and conſequently $f + g + g - f\ (= 2g) = q + e^2 + \frac{r}{e}$, and $g = \frac{q + e^2 + \frac{r}{e}}{2}$, the ſame way, you will find, by ſubtraction, &c. $f = \frac{q + e^2 - \frac{r}{e}}{2}$, and $f \times g\ (= s) = \frac{1}{4} \times q^2 + 2qe^2 + e^4 - \frac{r^2}{e^2}$; and multiplying by $4e^2$, and ranging the terms, you have this equation,

$$e^6 + 2qe^4 + \overline{q^2 - 4s} \times e^2 - r^2 = 0.$$

Suppoſe $e^2 = y$, and it becomes $y^3 + 2qy^2 + q^2$





$q^2-4y-r^2=0$, a cubic equation whose roots are to be discovered by the preceding articles. Then the values of $y$ being found, their square roots will give $e$ (since $y=e^2$); and having $e$, you will find $f$ and $g$ from the equations $f=\frac{q+e^2-\frac{r}{e}}{2}$, $g=\frac{q+e^2+\frac{r}{e}}{2}$. Lastly, extracting the roots of the equations $x^2+ex+f=0$, $x^2-ex+g=0$, you will find the four roots of the biquadratic $x^4+qx^2+rx+s=0$; for either $x=-\frac{1}{2}e\pm\sqrt{\frac{1}{4}e^2-f}$, or, $x=+\frac{1}{2}e\pm\sqrt{\frac{1}{4}e^2-g}$.

§ 83. Or if you want to find the roots of the biquadratic without taking away the second term; suppose it to be of this form,

$$\left.\begin{matrix}x^4-4px^3-2q\\+4p^2\end{matrix}\right\}\left.\begin{matrix}x^2-8r\\+4pq\end{matrix}\right\}\left.\begin{matrix}x-4s\\+q^2\end{matrix}\right\}=0,$$

and the values of $x$ will be

$$\left.\begin{matrix}x=p-a\pm\sqrt{p^2+q-a^2-\frac{2r}{a}}\\ \text{and } x=p+a\pm\sqrt{p^2+q-a^2+\frac{2r}{a}}\end{matrix}\right\}\text{; where}$$

$a^2$ is equal to the root of the cubic,

$$\left.\begin{matrix}y^3-p^2\\-q\end{matrix}\right\}\left.\begin{matrix}y^2+2pr\\+s\end{matrix}\right\}y-r^2=0.$$

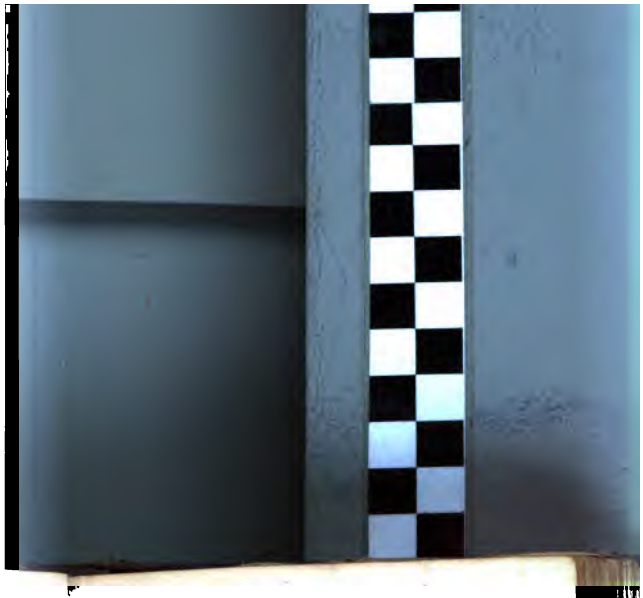
The demonstration is reduced from the last article, as the 78th is from the preceding.

## CHAP. IX.

### Of the Methods by which you may approximate to the roots of *numeral* Equations by their limits.

§ 84. WHEN any equation is propoſed to be reſolved, firſt find the limits of the roots (by *Chap.* 5.) as for example, if the roots of the equation $x^2 - 16x + 55 = 0$ are required, you find the limits are 0, 8, and 17, by § 48; that is, the leaſt root is between 0 and 8, and the greateſt between 8 and 17.

In order to find the firſt of the roots, I conſider that if I ſubſtitute 0 for $x$ in $x^2 - 16x + 55$, the reſult is poſitive, *viz.* + 55, and conſequently any number betwixt 0 and 8 that gives a poſitive reſult, muſt be leſs than the leaſt root, and any number that gives a negative reſult, muſt be greater. Since 0 and 8 are the limits, I try 4, that is, the mean betwixt them, and ſuppoſing $x = 4$, $x^2 - 16x + 55 = 16 - 64 + 55 = 7$, from which I conclude that the root is greater than 4. So that now we have the root limited between 4 and 8. Therefore I next try 6, and ſubſtituting it for $x$ we find $x^2 - 16x + 55 = 36 - 96 + 55 = -5$; which reſult being negative, I conclude that 6 is greater than the root required, which therefore is limited now between 4 and





and 6. And ſubſtituting 5, the mean between them in place of $x$, I find $x^2 - 16x + 55 = 25 - 80 + 55 = 0$; and conſequently 5 is the leaſt root of the equation. After the ſame manner you will diſcover 11 to be the greateſt root of that equation.

§ 85. Thus by diminiſhing the greater, or increaſing the leſſer limit, you may diſcover the true root when it is a commenſurable quantity. But by proceeding after this manner, when you have two limits, the one greater than the root, the other leſſer, that differ from one another but by unit, then you may conclude the root is *incommenſurable*.

We may however, by continuing the operation in fractions, approximate to it. As if the equation propoſed is $x^2 - 6x + 7 = 0$, if we ſuppoſe $x = 2$, the reſult is $4 - 12 + 7 = -1$, which being negative, and the ſuppoſition of $x = 0$ giving a poſitive reſult, it follows that the root is betwixt 0 and 2. Next we ſuppoſe $x = 1$; whence $x^2 - 6x + 7 = 1 - 6 + 7 = +2$, which being poſitive, we infer the root is betwixt 1 and 2, and conſequently incommenſurable. In order to approximate to it, we ſuppoſe $x = 1\frac{1}{2}$, and find $x^2 - 6x + 7 = 2\frac{1}{4} - 9 + 7 = \frac{1}{4}$; and this reſult being poſitive, we infer the root muſt be betwixt 2 and $1\frac{1}{2}$. And therefore we

try $1\frac{1}{2}$, and find $x^2 - 6x + 7 = \frac{49}{16} - \frac{42}{4} + 7$ $= 3\frac{1}{16} - 10\frac{8}{16} + 7 = -\frac{7}{16}$, which is negative; so that we conclude the root to be betwixt $1\frac{1}{2}$ and $1\frac{1}{4}$. And therefore we try next $1\frac{3}{8}$, which giving also a negative result, we conclude the root is betwixt $1\frac{1}{2}$ (or $1\frac{4}{8}$) and $1\frac{3}{8}$. We try therefore $1\frac{7}{16}$, and the result being positive, we conclude that the root must be betwixt $1\frac{7}{16}$ and $1\frac{6}{16}$, and therefore is nearly $1\frac{13}{32}$.

§ 86. Or you may approximate more easily by transforming the equation proposed into another whose roots shall be equal to 10, 100, or 1000 times the roots of the former (by § 29.) and taking the limits greater in the same proportion. This transformation is easy; for you are only to multiply the second term by 10, 100, or 1000, the third term by their squares, the fourth by their cubes, *&c.* The equation of the last example is thus transformed into $x^2 - 600x + 70000 = 0$, whose roots are 100 times the roots of the proposed equation, and whose limits are 100 and 200. Proceeding as before, we try 150, and find $x^2 - 600x + 70000 = 22500 - 90000 + 70000 = 2500$, so that 150 is less than the root. You next try 175, which giving a negative result must be greater than the root: and thus proceeding you find the root to be betwixt 158 and 159: from which you

you infer that the leaſt root of the propoſed equation $x^3 - 6x + 7 = 0$ is betwixt 1.58 and 1.59, being the hundreth part of the root of $x^3 - 600x + 70000 = 0$.

§ 87. If the cubic equation $x^3 - 15x^2 + 63x - 50 = 0$ is propoſed to be reſolved, the equation of the limits will be (by § 48) $3x^2 - 30x + 63 = 0$, or $x^2 - 10x + 21 = 0$, whoſe roots are 3, 7; and by ſubſtituting 0 for $x$ the value of $x^3 - 15x^2 + 63x - 50$ is negative, and by ſubſtituting 3 for $x$, that quantity becomes poſitive, $x = 1$ gives it negative, and $x = 2$ gives it poſitive, ſo that the root is between 1 and 2, and therefore incommenſurable. You may proceed as in the foregoing examples to approximate to the root. But there are other methods by which you may do that more eaſily and readily; which we proceed to explain.

§ 88. When you have diſcovered the value of the root to leſs than an unit (as in this example, you know it is a little above 1) ſuppoſe the difference betwixt its real value and the number that you have found nearly equal to it, to be repreſented by $f$; as in this example. Let $x = 1 + f$. Subſtitute this value for $x$ in this equation, thus,

$$\begin{aligned} x^3 &= 1 + 3f + 3f^2 + f^3 \\ -15x^2 &= -15 - 30f - 15f^2 \\ +63x &= 63 + 63f \\ -50 &= -50 \end{aligned}$$

$x^3 - 15x^2 + 63x - 50 = -1 + 36f - 12f^2 + f^3 = 0$.

Now becauſe $f$ is ſuppoſed leſs than unit, its powers $f^2$, $f^3$, may be neglected in this approximation; ſo that aſſuming only the two firſt terms we have $-1+36f=0$, or, $f=\frac{1}{36}=.027$; ſo that $x$ will be nearly 1.027.

You may have a nearer value of $x$ by conſidering, that ſeeing $-1+36f-12f^2+f^3=0$, it follows that

$$f=\frac{1}{36-12f+f^2}$$ (by ſubſtituting $\frac{1}{36}$ for $f$)

$$\text{nearly}=\frac{1}{36-12\times\frac{1}{36}+\frac{1}{36}\times\frac{1}{36}}=\frac{1296}{46225}=.02803.$$

§ 89. But the value of $f$ may be corrected and determined more accurately by ſuppoſing $g$ to be the difference betwixt its real value, and that which we laſt found nearly equal to it. So that $f=.02803+g$. Then by ſubſtituting this value for $f$ in the equation $f^3-12f^2+36f-1=0$, it will ſtand as follows,

$$\left.\begin{array}{rl} f^3= & 0.000022026+0.002357g+0.0849g^2+g^3 \\ -12f^2= & -.009428\,16\quad -0.672\,72g\quad -12g^2 \\ +36f= & 1.009\,08\qquad +36g \\ -1= & -1. \end{array}\right\}=0$$

$$=-0.000326\,1374+35.329637g-11.9195g^2+g^3=0.$$

Of which the firſt two terms, neglecting the reſt, give $35.329637\times g=0.000326\,1374$, and $g=.\frac{0003261374}{35.329637}=0.00000923127$. So that $f=0.028039231\,27$; and $x=1+f=1.028039231\,27$; which is very near the true root of the equation that was propoſed.

If

If ſtill a greater degree of exactneſs is required, ſuppoſe $b$ equal to the difference betwixt the true value of $g$, and that we have already found, and proceeding as above you may correct the value of $g$.

§ 90. For another example; let the equation to be reſolved be $x^3 - 2x - 5 = 0$, and by ſome of the preceding methods you diſcover one of the roots to be between 2 and 3. Therefore you ſuppoſe $x = 2 + f$, and ſubſtituting this value for it, you find

$$\left.\begin{array}{rl} x^3 = & 8 + 12f + 6f^2 + f^3 \\ -2x = & -4 - 2f \\ -5 = & -5 \end{array}\right\} = 0$$

$$= -1 + 10f + 6f^2 + f^3;$$

from which we find that $10f = 1$ nearly, or $f = 0.1$. Then to correct this value, we ſuppoſe $f = 0.1 + g$, and find

$$\left.\begin{array}{rl} f^3 = & 0.001 + 0.03g + 0.3g^2 + g^3 \\ 6f^2 = & 0.06 + 1.2\,g + 6.\,g^2 \\ 10f = & 1. \quad + 10.\,g \\ -1 = & -1. \end{array}\right\} = 0$$

$$= 0.061 + 11.23g + 6.3g^2 + g^3,$$

ſo that $g = \frac{-0.061}{11.23} = -0.0054$.

Then by ſuppoſing $g = -.0054 + b$, you may correct its value, and you will find that the root required is nearly 2.09455147.

§ 91.

§ 91. It is not only one root of an equation that can be obtained by this method, but, by making uſe of the other limits, you may diſcover the other roots in the ſame manner. The equation of § 87, $x^3 - 15x^2 + 63x - 50 = 0$, has for its limits 0, 3, 7, 50. We have already found the leaſt root to be nearly 1.028039. If it is required to find the middle root, you proceed in the ſame manner to determine its neareſt limits to be 6 and 7; for 6 ſubſtituted for $x$ gives a poſitive, and 7 a negative reſult. Therefore you may ſuppoſe $x = 6 + f$, and by ſubſtituting this value for $x$ in that equation, you find $f^3 + 3f^2 - 9f + 4 = 0$, ſo that $f = \frac{4}{9}$ nearly. Or ſince $f = \frac{4}{9 + 3f - f^2}$, it is (by ſubſtituting $\frac{4}{9}$ for $f$) $f = \frac{4}{9 - \frac{4}{3} - \frac{16}{81}} = \frac{324}{605}$, whence $x = 6 + \frac{324}{605}$ nearly. Which value may ſtill be corrected as in the preceding articles. After the ſame manner you may approximate to the value of the higheſt root of the equation.

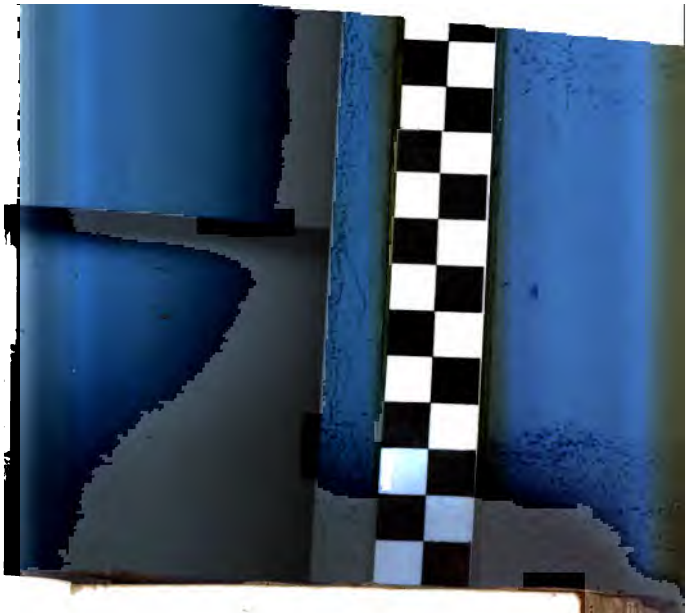
§ 92. "In all theſe operations, you will approximate ſooner to the value of the root, if you take the three laſt terms of the equation, and extract the root of the quadratic equation conſiſting of theſe three terms."

Thus, in § 88, inſtead of the two laſt terms of the equation $f^3 - 12f^2 + 36f - 1 = 0$, if you



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you take the three laſt and extract the root of the quadratic $12f^2 - 36f + 1 = 0$, you will find $f = .028031$, which is much nearer the true value than what you diſcover by ſuppoſing $36f - 1 = 0$.

It is obvious that this method extends to all equations.

§ 93. "By aſſuming equations affected with general coefficients, you may, by this method, deduce General Rules or *Theorems* for approximating to the roots of propoſed equations of whatever degree."

Let $f^3 - pf^2 + qf - r = 0$ repreſent the equation by which the fraction $f$ is to be determined, which is to be added to the limit, or ſubtracted from it, in order to have the near value of $x$. Then $qf - r = 0$ will give $f = \frac{r}{q}$. But ſince $f = \frac{r}{f^2 - pf + q}$, by ſubſtituting $\frac{r}{q}$ for $f$, we have this Theorem for finding $f$ nearly, *viz.*

$$f = \frac{r}{\frac{r^2}{q^2} - \frac{pr}{q} + q} = \frac{q^2 \times r}{q^3 - pqr + r^2}.$$

After the ſame manner, if it is a biquadratic, by which $f$ is to be determined, as $f^4 - pf^3 + qf^2 - rf + s = 0$, then $f$ being very little, we ſhall have $f = \frac{s}{r}$; which value is corrected by conſidering

fidering that $f = \frac{s}{r - qf + pf^2 - f^3}$ (by ſubſtituting $\frac{s}{r}$ for $f$) $= \frac{s}{r - \frac{qs}{r} + \frac{ps^2}{r^2} - \frac{s^3}{r^3}}$, whence we have this Theorem for all biquadratic equations,

$$f = \frac{r^3 \times s}{-s^3 + ps^2r - qsr^2 + r^4}.$$

§ 94. Other Theorems may be deduced by aſſuming the three terms of the equation, and extracting the root of the quadratic which they form.

Thus, to find the value of $f$ in the equation $f^3 - pf^2 + qf - r = 0$ where $f$ is ſuppoſed to be very little, we neglect the firſt term $f^3$, and extract the root of the quadratic $pf^2 - qf + r = 0$, or of $f^2 - \frac{q}{p} \times f + \frac{r}{p} = 0$; and we find $f = \frac{q}{2p} \pm \sqrt{-\frac{r}{p} + \frac{q^2}{4p^2}} = \frac{q \pm \sqrt{q^2 - 4pr}}{2p}$ nearly.

But this value of $f$ may be corrected by ſuppoſing it equal to $m$, and ſubſtituting $m^3$ for $f^3$ in the equation $f^3 - pf^2 + qf - r = 0$, which will give $m^3 - pf^2 + qf - r = 0$, and $pf^2 - qf + r - m^3 = 0$; the reſolution of which quadratic equation gives $f = \frac{q \pm \sqrt{q^2 - 4pr + 4pm^3}}{2p}$, very near the true value of $f$.

After the ſame manner you may find like Theorems for the roots of biquadratic equations, or of equations of any dimenſion whatever.

§ 95.

§ 95. In general, let $x^n + px^{n-1} + qx^{n-2} + rx^{n-3} +$, &c. $+A = 0$ repreſent an equation of any dimenſions $n$, where $A$ is ſuppoſed to repreſent the abſolute known term of the equation. Let $k$ repreſent the limit next leſs than any of the roots, and ſuppoſing $x = k + f$, ſubſtitute the powers of $k + f$ inſtead of the powers of $x$, and there will ariſe $\overline{k+f}^n + p \times \overline{k+f}^{n-1} + q \times \overline{k+f}^{n-2} + r \times \overline{k+f}^{n-3}$, &c. $+A = 0$, or by involution, diſpoſing the terms according to the dimenſions of $f$ . . . . . .

$$\left.\begin{array}{l} f^n + nk^{n-1} \times f + n \times \frac{n-1}{2} k^{n-2} f^2 +, \text{ &c.} \\ pk^{n-1} + p \times n-1 k^{n-2} \times f + p \times \frac{n-1}{2} \times \frac{n-2}{2} k^{n-3} f^3 +, \text{ &c.} \\ qk^{n-2} + q \times n-2 k^{n-3} \times f + q \times \frac{n-2}{2} \times \frac{n-3}{2} k^{n-4} f^4 +, \text{ &c.} \\ rk^{n-3} + r \times n-3 k^{n-4} \times f + r \times \frac{n-3}{2} \times \frac{n-4}{2} k^{n-5} f^5 +, \text{ &c.} \end{array}\right\} + A = 0,$$

&c.

where

where neglecting all the powers of $f$ after the first two terms, you find

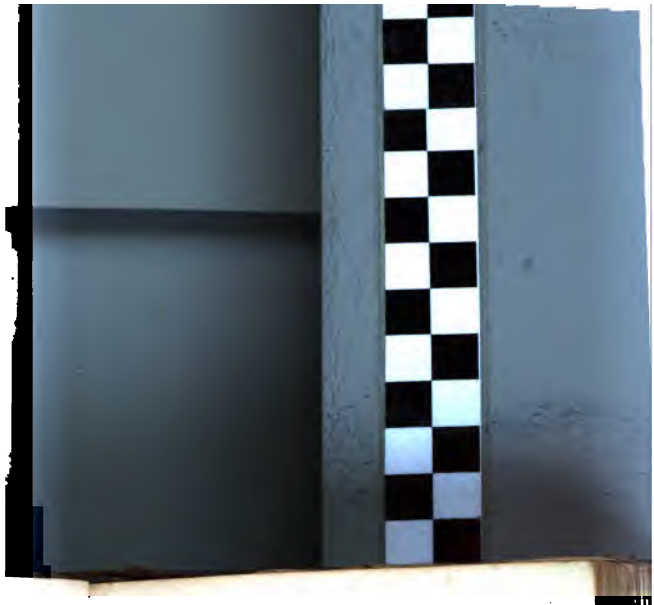
$$x = (z+f) = \overline{z^n} + \frac{n}{1}\overline{z^{n-1}}f + \frac{n \times n-1}{1 \times 2}\overline{z^{n-2}}ff + \frac{n \times n-1 \times n-2}{1 \times 2 \times 3}\overline{z^{n-3}}f^3 + \&c.$$

and

$$f = \frac{x - \overline{z^n}}{n\overline{z^{n-1}} + \frac{n \times n-1}{1 \times 2}\overline{z^{n-2}}f + \frac{n \times n-1 \times n-2}{1 \times 2 \times 3}\overline{z^{n-3}}ff + \&c.} = \frac{x - \overline{z^n}}{n\overline{z^{n-1}} + \frac{n \times n-1}{1 \times 2}\overline{z^{n-2}}f + \frac{n \times n-1 \times n-2}{1 \times 2 \times 3}\overline{z^{n-3}}ff + \&c.}$$

whence particular Theorems for extracting the roots of equations may be deduced.

§ 96. "By this method you may discover Theorems for approximating to the roots of *pure*





*pure powers*;" as to find the $n$ root of any number $A$; ſuppoſe $k$ to be the neareſt leſs root in integers, and that $k+f$ is the true root, then ſhall $k^n + nk^{n-1}f + n \times \frac{n-1}{2} k^{n-2}f^2$, &c. $= A$; and, aſſuming only the two firſt terms,

$f = \frac{A-k^n}{nk^{n-1}}$: or, more nearly, taking the three firſt terms,

$f = \frac{A-k^n}{nk^{n-1} + n \times \frac{n-1}{2} k^{n-2}f}$, and (taking $\frac{A-k^n}{nk^{n-1}} = f$)

$$f = \frac{A-k^n}{nk^{n-1} + \frac{n^2-n}{2} k^{n-2} \times \frac{A-k^n}{nk^{n-1}}} = \frac{A-k^n}{nk^{n-1} + \frac{n-1}{2k} \times A-k^n}$$

(putting $m = A - k^n$) $= \frac{km}{nk^n + \frac{n-1}{2} \times m}$; which is a *rational* Theorem for approximating to $f$.

You may find an *irrational* Theorem for it, by aſſuming the three firſt terms of the power of $k+f$, viz. $k^n + nk^{n-1}f + n \times \frac{n-1}{2} k^{n-2}f^2 = A$.

For $nk^{n-1}f + n \times \frac{n-1}{2} k^{n-2}f^2 = A - k^n = m$; and reſolving this quadratic equation, you find

$$f = -\frac{k}{n-1} \pm \sqrt{\frac{2m}{n \times \overline{n-1} \times k^{n-2} + \frac{k^2}{\overline{n-1}^2}}} =$$

$$-\frac{k}{n-1} \pm \sqrt{\frac{2mn-2m+nk^n}{n \times \overline{n-1}^2 k^{n-2}}}.$$

In

In the application of theſe Theorems, when a near value of $f$ is obtained, then adding it to $k$, ſubſtitute the aggregate in place of $k$ in the formula, and you will by a new operation, obtain a more correct value of the root required; and, by thus proceeding, you may arrive at any degree of exactneſs.

Thus to obtain the cube root of 2, ſuppoſe $k = 1$, and $f\ (= \frac{km}{nk^n + \frac{n-1}{2}m}) = \frac{1}{4} = 0.25$. In the ſecond place, ſuppoſe $k = 1.25$, and $f$ will be found, by a new operation, equal to 0.009921, and conſequently, $\sqrt[3]{2} = 1.259921$ nearly. By the irrational Theorem, the ſame value is diſcovered for $\sqrt[3]{2}$.

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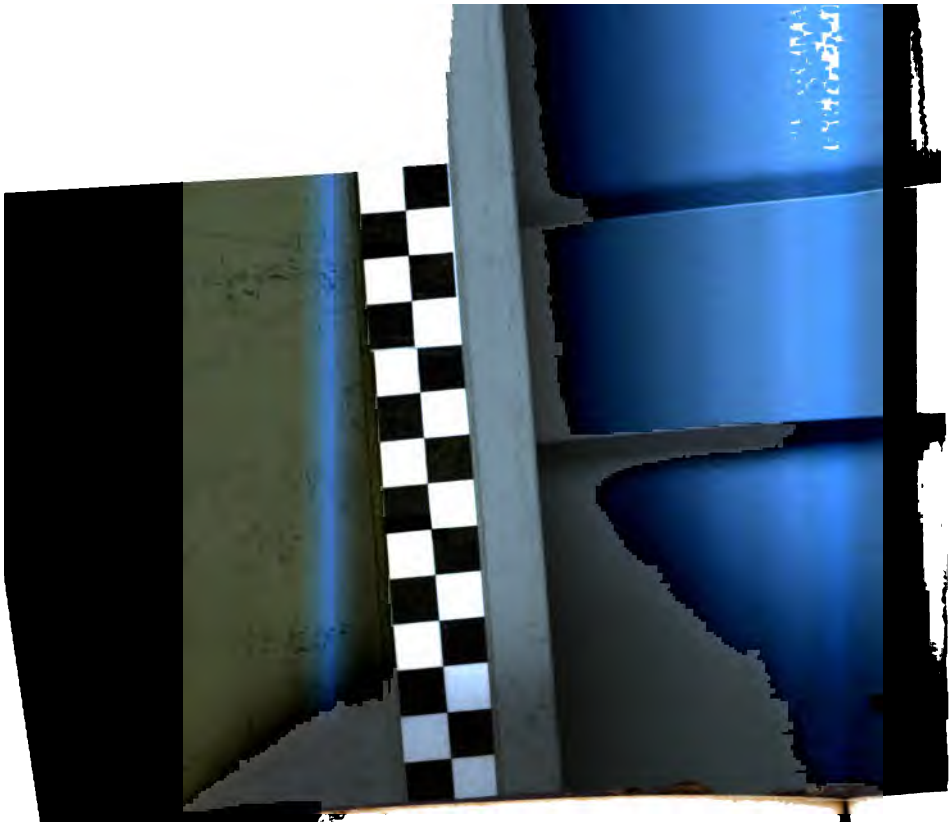
## CHAP. X.

### Of the Method of *Series* by which you may approximate to the roots of *literal* equations.

§ 97. IF there be only two letters, $x$ and $a$, in the propoſed equation, ſuppoſe $a$ equal to unit, and find the root of the numeral equation that ariſes from the ſubſtitution, by the rules of the laſt chapter. Multiply theſe roots by $a$, and the products will give the roots of the propoſed equation.

Thus the roots of the equation $x^2-16x+55=0$ are found, in § 84, to be 5 and 11. And therefore the roots of the equation $x^2-16ax+55a^2=0$, will be $5a$ and $11a$. The roots of the equation $x^3+a^2x-2a^3=0$ are found by enquiring what are the roots of the numeral equation $x^3+x-2=0$, and ſince one of theſe is 1, it follows that one of the roots of the propoſed equation is $a$; the other two are *imaginary*.

§ 98. If the equation to be reſolved involves more than two letters, as $x^3+a^2x-2a^3+ayx-y^3=0$, then the value of $x$ may be exhibited in a ſeries having its terms compoſed of the powers of $a$ and $y$ with their reſpective coef-





ficients; which will "*converge the ſooner the leſs y is in reſpect of a, if the terms are continually multiplied by the powers of y, and divided by thoſe of a.*" Or, "will *converge the ſooner the greater y is in reſpect of a, if the terms be continually multiplied by the powers of a, and divided by thoſe of y.*" Since when $y$ is very little in reſpect of $a$, the terms $y$, $\frac{y^2}{a}$, $\frac{y^3}{a^2}$, $\frac{y^4}{a^3}$, $\frac{y^5}{a^4}$, &c. decreaſe very quickly. If $y$ vaniſh in reſpect of $a$, the ſecond term will vaniſh in reſpect of the firſt, ſince $\frac{y^2}{a} : y :: y : a$. And after the ſame manner $\frac{y^2}{a^2}$ vaniſhes in reſpect of the term immediately preceding it.

But when $y$ is vaſtly great in reſpect of $a$, then $a$ it vaſtly great in reſpect of $\frac{a^2}{y}$, and $\frac{a^2}{y}$ in reſpect of $\frac{a^2}{y^2}$; ſo that the terms $a$, $\frac{a^2}{y}$, $\frac{a^3}{y^2}$, $\frac{a^4}{y^3}$, $\frac{a^5}{y^4}$, &c. in this caſe *decreaſe* very ſwiftly. In either caſe, the ſeries converge ſwiftly that conſiſt of ſuch terms; and a few of the firſt terms will give a near value of the root required.

§ 99. If a ſeries for $x$ is required from the propoſed equation that ſhall converge the ſooner, the leſs $y$ is in reſpect of $a$; to find the firſt term of this ſeries, we ſhall ſuppoſe $y$ to vaniſh; and extracting the root of the equation

$x^3$

ts; which will "converge the sooner the
respect of a, if the terms are continu
ied by the powers of y, and divide
a." Or, "will converge the sooner
y is in respect of a, if the terms be
multiplied by the powers of a, and divi
of y." Since when y is very little

of a, the terms $y, \frac{y^2}{a}, \frac{y^3}{a^2}, \frac{y^4}{a^3}, \frac{y^5}{a^4}$, &c.

very quickly. If y vanish in respect
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since $\frac{y^2}{a} : y :: y : a$. And when

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stly great in respect of $\frac{a^2}{y}$, and $\frac{a^3}{y^2}$

$\frac{a^3}{y^3}$; so that the terms $a, \frac{a^2}{y}, \frac{a^3}{y^2}, \frac{a^4}{y^3}$

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$p^3$



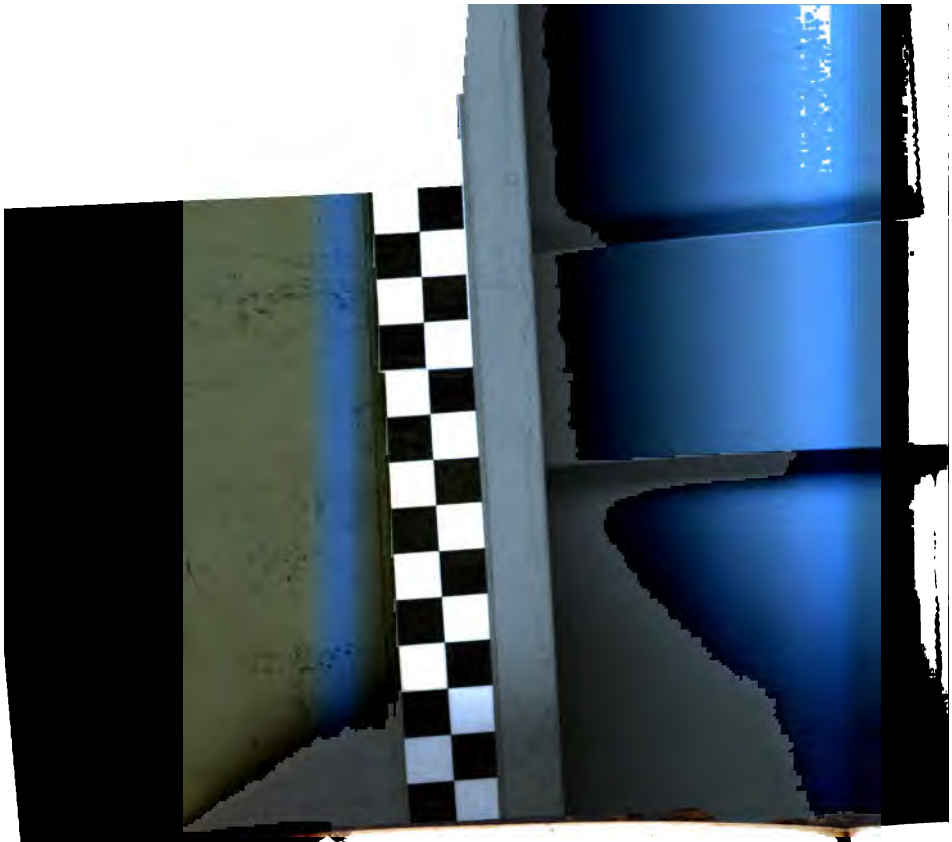
$x^3 + a^2x - 2a^3 = 0$, consisting of the remaining parts of the equation that do not vanish with $y$, we find, by § 97, that $x = a$; which is the true value of $x$ when $y$ vanishes, but is only near its value when $y$ does not vanish, but only is very little. To get a value still nearer the true value of $x$, suppose the difference of $a$ from the true value to be $p$, or that $x = a + p$. And substituting $a + p$ in the given equation for $x$, you will find,

$$\left.\begin{array}{l} x^3 = a^3 + 3a^2p + 3ap^2 + p^3 \\ +a^2x = a^3 + a^2p \\ -2a^3 = -2a^3 \\ +ayx = a^2y + apy \\ -y^3 = -y^3 \end{array}\right\} = 0$$

$$\left.\begin{array}{l} = 4a^2p + 3ap^2 + p^3 \\ a^2y + apy - y^3 \end{array}\right\} = 0.$$

But since, by supposition, $y$ and $p$ are very little in respect of $a$, it follows that the terms $4a^2p$, $a^2y$, where $y$ and $p$ are separately of the *least* dimensions, are vastly great in respect of the rest; so that, in determining a near value of $p$, the rest may be neglected: and from $4a^2p + a^2y = 0$, we find $p = -\frac{1}{4}y$. So that $x = a + p = a - \frac{1}{4}y$, nearly.

Then to find a nearer value of $p$, and consequently of $x$, suppose $p = -\frac{1}{4}y + q$, and substituting this value for it in the last equation, you will find,





$$\left.\begin{array}{rl} p^3 = & -\frac{1}{64}y^3 + \frac{3}{16}y^2q - \frac{1}{4}yq^2 + q^3 \\ 3ap^2 = & -\frac{1}{16}ay^2 - \frac{3}{4}ayq + 3aq^2 \\ 4a^2p = & -a^2y + 4a^2q \\ ayp = & -\frac{1}{4}ay^2 + ayq \\ a^2y = & a^2y \\ -y^3 = & -y^3 \end{array}\right\} = 0$$

$$= -\frac{61}{64}y^3 + \frac{3}{16}y^2q - \frac{1}{4}yq^2 + q^3 \left.\begin{array}{l} \\ -\frac{1}{16}ay^2 - \frac{1}{4}ayq + 3aq^2 \\ +4a^2q \end{array}\right\} = 0.$$

And since, by the ſuppoſition, $q$ is very little in reſpect of $p$, which is nearly $= -\frac{1}{4}y$, therefore $q$ will be very little in reſpect of $y$; and conſequently all the terms of the laſt equation will be very little in reſpect of theſe two, *viz.* $-\frac{1}{16}ay^2$, $+4a^2q$, where $y$ and $q$ are of leaſt dimenſions ſeparately: particularly the term $-\frac{1}{4}ayq$ is little in reſpect of $4a^2q$, becauſe $y$ is very little in reſpect of $a$; and it is little in reſpect of $-\frac{1}{16}ay^2$, becauſe $q$ is little in reſpect of $y$.

Neglect therefore the other terms and ſuppoſing $-\frac{8}{16}ay^2 + 4a^2q = 0$, you will have $q = \frac{1}{64} \times \frac{y^2}{a}$; ſo that $x = a - \frac{1}{4}y + \frac{1}{64} \times \frac{y^2}{a}$. And by proceeding in the ſame manner you will find $x = a - \frac{y}{4} + \frac{y^2}{64a} - \frac{131y^3}{512a^2} + \frac{5099^4}{16384a^3} -$, &c.

§ 100. When it is required to find a ſeries for $x$ that ſhall converge ſooner, the *greater* $y$ is in





$$\left.\begin{array}{l} = -\frac{5}{64}y^3 + \frac{3}{16}y^2q - \frac{1}{4}yq^2 + q^3 \\ = \frac{1}{16}ay^2 - \frac{3}{8}ayq + 3aq^2 \\ = -a^2y + 4a^2q \\ = -\frac{1}{4}ay^2 + ayq \\ \quad a^2y \\ \quad -y^3 \end{array}\right\} = 0$$

$$\left.\begin{array}{l} -\frac{5}{64}y^3 + \frac{3}{16}y^2q - \frac{1}{4}yq^2 + q^3 \\ -\frac{1}{16}ay^2 - \frac{3}{4}ayq + 3aq^2 \\ +4a^2q \end{array}\right\} = 0.$$

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$+ 4a^2q$, where $y$ and $q$ are of lit
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little in reſpect of $4a^2q$, becauſe $y$
in reſpect of $a$; and it is little
$-\frac{1}{16}ay^2$, becauſe $q$ is little in reſpe

therefore the other terms and ſo
$\frac{5}{64}ay^2 + 4a^2q = 0$, you will ha
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ıceeding in the ſame manner you wi
$-\frac{y}{4} + \frac{y^2}{64a} - \frac{131y^3}{512a^2} + \frac{509y^4}{16384a^3}$

When it is required to find a ſeries
ıall converge ſooner, the greater $y$ is





in reſpect of any quantity $a$, you need only ſuppoſe $a$ to be very little in reſpect of $y$, and proceed by the ſame reaſoning as in the laſt example on the ſuppoſition of $y$ being very little.

Thus, to find a value for $x$ in the equation $x^3 - a^2x + ayx - y^3 = 0$ that ſhall converge the ſooner the greater $y$ is in reſpect of $a$, ſuppoſe $a$ to vaniſh, and the remaining terms will give $x^3 - y^3 = 0$, or $x = y$. So that when $y$ is vaſtly great, it appears that $x = y$ nearly.

But to have the value of $x$ more accurately, put $x = y + p$, then

$$\left.\begin{array}{rl} x^3 = & y^3 + 3y^2p + 3yp^2 + p^3 \\ -a^2x = & -a^2y - a^2p \\ +ayx = & ay^2 + ayp \\ -y^3 = & -y^3 \end{array}\right\} = 0$$

$$= +3y^2p + 3yp^2 + p^3 - a^2y - a^2p + ay^2 + ayp :$$

where the terms $3y^2p + ay^2$ become vaſtly greater than the reſt, $y$ being vaſtly greater than $a$ or $p$; and conſequently $p = -\frac{1}{3}a$ nearly.

Again, by ſuppoſing $p = -\frac{1}{3}a + q$, you will transform the laſt equation into

$$\left.\begin{array}{l} -\frac{5}{27}a^3 + 3y^2q + 3yq^2 + q^3 \\ -a^2y - ayq - aq^2 \\ \quad -\frac{2}{3}a^2q \end{array}\right\} = 0;$$

where the two terms $3qy^2 - a^2y$ muſt be vaſtly greater than any of the reſt, $a$ being vaſtly leſs

than $y$, and $q$ vaſtly leſs than $a$, by the ſuppoſition; ſo that $3qy^3 - a^2y = 0$, and $q = \frac{a^2}{3y}$ nearly. By proceeding in this manner, you may correct the value of $y$, and find that

$$x = y - \tfrac{1}{3}a + \frac{a^2}{3y} + \frac{a^3}{81y^2} - \frac{8a^4}{243y^3}, \text{ \&c.}$$

which ſeries converges the ſooner the greater $y$ is ſuppoſed to be taken in reſpect of $a$.

§ 101. In the ſolution of the firſt *Example* thoſe terms were always compared in order to determine $p$, $q$, $r$, &c. in which $y$ and thoſe quantities $p$, $q$, $r$, &c. were *ſeparately* of feweſt dimenſions. But in the ſecond *Example*, thoſe terms were compared in which $a$ and the quantities $p$, $q$, $r$, &c. were of leaſt dimenſions ſeparately. And theſe always are the proper terms to be compared together, becauſe they become vaſtly greater than the reſt, in the reſpective hypotheſes.

*In general*; to determine the firſt, or any, term in the ſeries, *ſuch terms of the equation are to be aſſumed together only, as will be found to become vaſtly greater than the other terms*; that is, which give a value of $x$, which ſubſtituted for it in all the terms of the equation ſhall raiſe the dimenſions of the other terms all above, or all below, the dimenſions of the aſſumed terms, according as $y$ is ſuppoſed to be vaſtly little, or vaſtly great in reſpect of $a$.

Thus

and $q$ vaſtly leſs than $a$, by the ſuppo-

ſo that $3qy^2 - a^2y = 0$, and $q =$

By proceeding in this manner, you

ue value of $y$, and find that

$y = \frac{1}{3}a + \frac{a^2}{3y} + \frac{a^3}{81y^2} - \frac{8a^4}{243y^3}$, &c.

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Thus to determine the firſt term of a converging ſeries expreſſing the value of $x$ in the laſt equation $x^3 - a^2x + ayx - y^3 = 0$, the terms $ayx$ and $-y^3$ are not to be compared together, for they would give $x = \frac{y^2}{a}$, which ſubſtituted for $x$, the equation becomes

$$\frac{y^6}{a^3} - ay^3 + y^3 - y^3 = 0,$$

where the firſt term is of more dimenſions than the aſſumed terms $ayx$, $-y^3$; and the ſecond of fewer; ſo that the two firſt terms cannot be neglected in reſpect of the two laſt, neither when $y$ is very great nor very little, compared with $a$. Nor are the terms $x^3$, $ayx$, fit to be compared together in order to obtain the firſt term of a ſeries for $x$, for the like reaſon.

But $x^3$ may be compared with $-a^2x$, as alſo $-a^2x$ with $-y^3$ for that end. Theſe two give the firſt term of a ſeries that converges the ſooner the leſs $y$ is; as $x^3 = y^3$ gives the firſt term of a ſeries that converges the ſooner the greater $y$ is. The laſt ſeries was given in the preceding article. The comparing $x^3$ with $-a^2x$ gives theſe two ſeries,

$$x = a - \tfrac{1}{2}y - \frac{y^2}{8a} + \frac{7y^3}{16a^2} - \frac{59y^4}{128a^3}, \text{ &c.}$$

$$x = -a + \tfrac{1}{2}y + \frac{y^2}{8a} + \frac{9y^3}{16a^2} + \frac{69y^4}{128a^3}, \text{ &c.}$$

The comparing $-a^2x$ with $-y^3$ gives

$$x = -\frac{y^3}{a^2} - \frac{y^4}{a^3} - \frac{y^5}{a^4} - \frac{y^6}{a^5} -, \text{ &c.}$$

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§ 102. It appears
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ſquare may expreſs its diſtance from the line AC. Of this ſquare we are to obſerve,




1. That the terms are not only in geometrical progreſſion in the vertical column AB, or the horizontal AC, and their parallels; but alſo in the terms taken in any oblique ſtraight line whatever; for in any ſuch terms it is manifeſt that the *indices* of $y$ and $x$ will be in arithmetical progreſſion. The indices of $y$, becauſe thoſe terms will remove equally from the line AC, or approach equally to it, and the indices

of

of $y$ in any ſuch terms are as their diſtances from that line AC. The indices of $x$ will alſo be in arithmetical progreſſion, becauſe theſe terms equally remove from, or approach to the line AB. Thus for example, in the terms $y^7$, $y^5x$, $y^3x^2$, $yx^3$, the indices of $y$ decreaſing by the common difference 2, while the indices of $x$ increaſe in the progreſſion of the natural numbers, the common ratio of the terms is $\frac{x}{y^2}$. It follows,

2. From the laſt obſervation, that "if any two terms be ſuppoſed equal, then all the terms in the ſame ſtraight line with theſe terms, will be equal;" becauſe by ſuppoſing theſe two terms equal, the common ratio is ſuppoſed to be a ratio of equality; and from this it follows, that "if you ſubſtitute every where for $x$ the value that ariſes for it by ſuppoſing any two terms equal, expreſſed in the powers of $y$, the dimenſions of $y$ in all the terms that are found in the ſame ſtraight line will be equal"; but "the dimenſions of $y$ in the terms *above* that line will be *greater* than in thoſe in that line;" and "the dimenſions of $y$ in the terms *below* the ſaid line will be *leſs* than its dimenſions in that line." Thus, by ſuppoſing $y^7 = yx^3$, we find $x^3 = y^6$, or $x = y^2$; and ſubſtituting this value for $x$ in all the ſquares, the dimenſions of $y$ in the terms $y^7$, $y^5x$, $y^3x^2$, $yx^3$, which are all found in the

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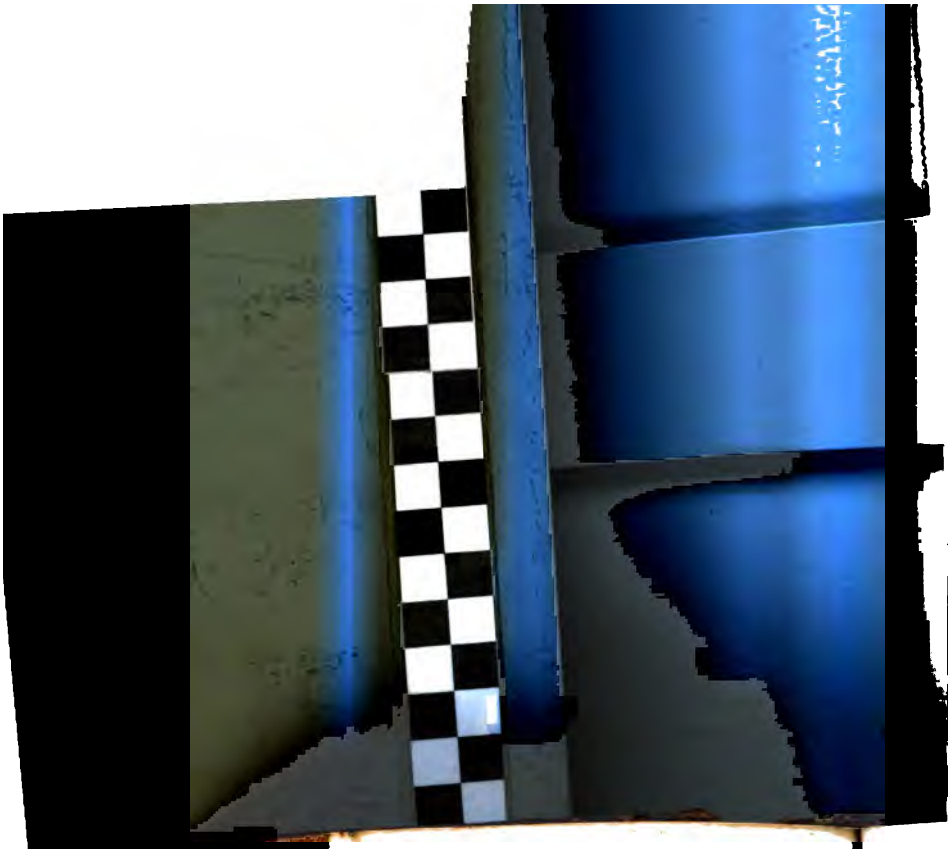


the ſame ſtraight line, will be 7, but the dimenſions in all the terms above that line will be more than 7, and in all the terms below that line will be leſs than 7.

§ 103. From theſe two obſervations we may eaſily find a method for diſcovering what terms ought to be aſſumed from an equation in order to give a value for $x$ which ſhall make the other terms all of *higher*, or all of *lower* dimenſions of $y$ than the aſſumed terms: *viz.* "after all the terms of the equation are ranged in their proper ſquares (by the laſt article) ſuch terms are to be aſſumed as lie in a ſtraight line, ſo that the other terms either lie all above the ſtraight line, or fall all below it."

For example, ſuppoſe the equation propoſed is $y^7 - ay^5x + y^4x^3 + a^3yx^4 - ax^6 = 0$, then marking with an aſteriſk the ſquares in the laſt article which contain the ſame dimenſions of $x$ and $y$ as the terms in the equation, imagine a ruler ZE to revolve about the firſt ſquare marked at $y^7$, and as it moves from A towards C, it will firſt meet the term $ay^5x$, and while the ruler joins theſe two terms, all the other terms lie above it: from which you infer, that by ſuppoſing theſe terms equal, you ſhall obtain a value of $x$, which ſubſtituted for it, will give all the other terms of higher dimenſions of $y$, than thoſe terms: and hence we conclude that the value of $x$ deduced from ſuppoſing theſe terms

equal,





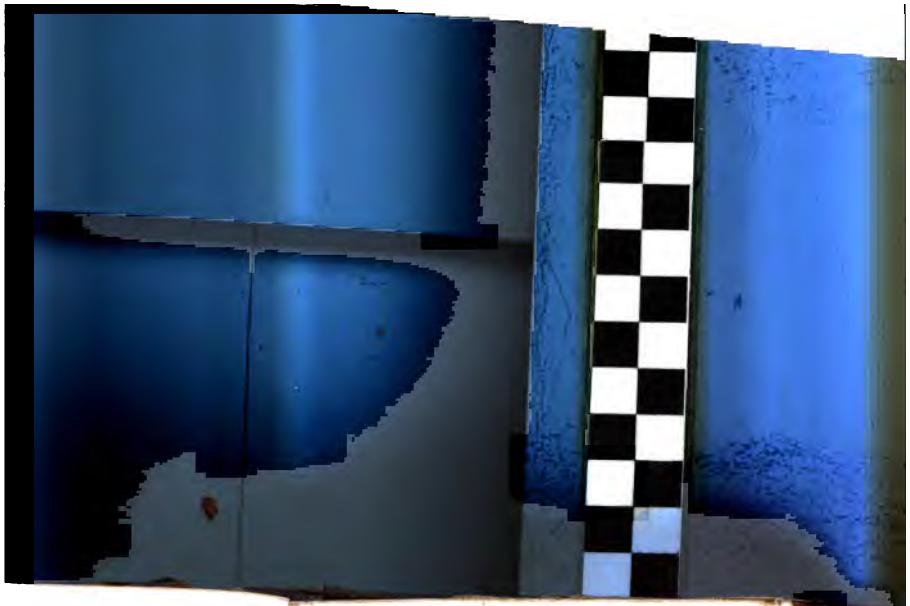
equal, *viz.* $\frac{y^2}{a}$, is the firſt term of a ſeries that will converge the ſooner the leſs $y$ is in reſpect of $a$.

If the ruler be made to revolve about the ſame ſquare the contrary way from D towards C, it will firſt meet the term $y^4x^2$, and by ſuppoſing $y^7 + y^4x^2 = 0$, we find $y = x$, which gives the firſt term of a ſeries for $x$, that converges the ſooner the greater that $y$ is. And this is the celebrated Rule invented by Sir *Iſaac Newton* for this purpoſe.

§ 104. This Rule may be extended to equations having terms that involve powers of $x$ and $y$ with *fractional* or *ſurd* indices; "by taking diſtances from A in the lines AC and AB proportional to theſe fractions and ſurds," and thence determining the ſituation of the terms of the propoſed equation in the parallelogram ABCD.

It is to be obſerved alſo, that when the line joining any two terms has all the other terms on one ſide of it, by them you may find the firſt term of a converging ſeries for $x$, and thus "various ſuch ſeries can be deduced from the ſame equation." As, in the laſt Example, the line joining $y^5x$ and $yx^4$ has all the terms above it; and therefore ſuppoſing $-ay^4x + a^5yx^4 = 0$, we find $x^3 = \frac{y^4}{a^4}$, and $x = \frac{y^{\frac{4}{3}}}{a^{\frac{4}{3}}}$, which is the firſt

term





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refore ſuppoſing $-ay^4x + a^5yx^4 = 0$

$: \frac{y^4}{a}$, and $x = \frac{y^{\frac{4}{1}}}{a^{\frac{1}{1}}}$, which is the firſt

term



term of another converging ſeries for $x$. Again, the ſtraight line joining $yx^4$ and $x^6$ has all the other terms above it, and therefore, ſuppoſing $a^5yx^4 - ax^6 = 0$, we find $ay = x^5$, and $x = a^{\frac{1}{5}}y^{\frac{1}{5}}$, the firſt term of another ſeries for $x$, converging alſo the ſooner the leſs $y$ is. There are two ſeries converging the ſooner the greater $y$ is, to be deduced from ſuppoſing $y^5 = -y^4x^1$, or $y^4x^1 = ax^6$. And, to find all theſe ſeries, "deſcribe a *polygon Zabed*, having a term of the equation in each of its angles, and including all the other terms within it, then a ſeries may be found for $x$, by ſuppoſing any two terms equal that are placed in any two adjacent angles of the polygon."

§ 105. If the ruler ZE be made to move parallel to itſelf, all the terms which it will touch at once will be of the ſame dimenſions of $y$: for they will bear the ſame proportion to one another as the terms in the line ZE themſelves. The terms which the Ruler will touch firſt will have fewer dimenſions of $y$, than thoſe it touches afterwards in the progreſs of its motion, if it moves towards D; but more dimenſions than they, if it moves towards A. The terms in the ſtraight line ZE, ſerve to determine the firſt term of the converging ſeries required. Theſe with the terms it touches afterwards ſerve to determine the ſucceeding terms of the converging

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and the ruler move

§ 106. The ſam
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greater than any o
equation. Suppoſe
the equation, and, b
is greater than $\frac{l-}{k}$
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an any other terms of the propoſe
Suppoſe $Fy^r x^t$ is any other term o
on, and, by the ſuppoſition, $\frac{l-m}{s} (= n)$
than $\frac{l-e}{k}$, and conſequently, mult
; you find $nk$ greater than $l-e$, and
er than $l$; now if for $x$ you ſubſtitute
$y^r x^t = FAy^{nk+e}$, which therefore will
pared with $Dy^l$ (ſince $nk+e$ is greater
n $y$ is infinitely little. Thus there
terms will vaniſh compared with
$x^s$ which are ſuppoſed equal; and
, they will give the firſt term of a
ill converge the ſooner the leſs $y$ is.

§ 107.



§ 107. If you obſerve "when $\frac{l-m}{s}$ is found *leaſt* of all, and ſuppoſe it equal to $n$, then will $Ay^n$ be the firſt term of a ſeries that will converge the ſooner the *greater* $y$ is." For in that caſe $Dy^l$ and $Ey^m x^s$ will be infinitely greater than $Fy^r x^t$, becauſe $\frac{l-m}{s} (= n)$ being leſs than $\frac{l-e}{k}$, it follows that $nk$ is leſs than $l-e$, and $nk+e$ leſs than $l$, and conſequently $Fy^r x^t (= FAy^{nk+e})$ vaſtly leſs than $Dy^l$, when $y$ is very great.

After the ſame manner, if you compare any term $Dy^l x^k$, where both $x$ and $y$ are found, with all the other terms, and obſerve where $\frac{l-m}{s-b}$ is found *greateſt* or *leaſt*, and ſuppoſe $\frac{l-m}{s-b} = n$, then may $Ay^n$ be the firſt term of a converging ſeries. For ſuppoſing that $Fy^r x^t$ is any other term of the equation, if $\frac{l-m}{s-b} (= n)$ is greater than $\frac{l-e}{k-b}$, then ſhall $nk-nb$ be greater than $l-e$, and $nk+e$ greater than $l+nb$. But $nk+e$ are the dimenſions of $y$ in $Fy^r x^t$ when $x = Ay^n$, and $l+nb$ are the dimenſions of $y$ in $Ey^m x^s$, therefore $Fy^r x^t$ is of more dimenſions of $y$ than $Ey^m x^s$, and therefore vaniſhes compared to it when $y$ is ſuppoſed infinitely little. In the ſame manner, if $\frac{l-m}{s-b}$ is leſs than $\frac{l-e}{k-b}$, then will

will $Ey^{m}x^{t}$ be infinitely greater than $Fy^{n}x^{t}$, when $y$ is infinite.

§ 108. When the firſt term ($Ay^{m}$) of the ſeries is found by the preceding method, then by ſuppoſing $x = Ay^{m} + p$, and ſubſtituting this binomial and its powers for $x$ and its powers, there will ariſe an equation for determining $p$ the ſecond term of the ſeries. This new equation may be treated in the ſame manner as the equation of $x$, and by the Rule of § 103, the terms that are to be compared in order to obtain a near value of $p$, may be diſcovered; by means of which terms $p$ may be found: which ſuppoſe equal to $By^{n+r}$, then by ſuppoſing $p = By^{n+r} + q$, the equation may be transformed into one for determining $q$ the third term of the ſeries, and by proceeding in the ſame manner you may determine as many terms of the ſeries as you pleaſe; finding $x = Ay^{m} + By^{n+r} + Cy^{m+2r} + Dy^{m+3r}$, &c. where the dimenſions of $y$ aſcend or deſcend according as $r$ is poſitive or negative; and always "in arithmetical progreſſion, that this value of $x$ being ſubſtituted for it in the propoſed equation, the terms involving $y$ and its powers may fall in with one another, ſo that more than one may always involve the ſame dimenſion of $y$, which may mutually deſtroy each other and make the whole equation vaniſh, as it ought to do."

It





$Ey^{m}x^{s}$ be infinitely greater than $Fy^{n}x^{t}$, whi
nite.

. When the first term ($Ay^{n}$) of the f
und by the preceding method, then i
$g\ x = Ay^{n} + p$, and substituting this fo
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it are to be compared in order to ob
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which terms $p$ may be found: whi
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$r + q$, the equation may be re
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he series, and by proceeding in the
ner you may determine as many term
es as you please; finding $x = Ay^{n}$
$Cy^{n+2r} + Dy^{n+3r}$, &c. where the e
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gression, that this value of $x$ being
for it in the proposed equation, th
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nother, so that more than one mem
olve the same dimension of $y$, which
lly destroy each other and make the
tion vanish, as it ought to do."



It is obvious that as the dimensions of $y$ in $Ay^{n} + By^{n+r} + Cy^{n+2r} + Dy^{n+3r}$, &c. are in an arithmetical progression whose difference is $r$, the square, cube, or any power $s$ of $Ay^{n} + By^{n+r} + Cy^{n+2r} + Dy^{n+3r} + \&c.$ will consist of terms wherein the dimensions of $y$ will constitute an arithmetical progression having the same common difference $r$; for these dimensions will be $sn$, $sn + r$, $sn + 2r$, $sn + 3r$, &c. Therefore, if in any term $Ey^{m}x^{s}$ you substitute for $x$ the series $Ay^{n} + By^{n+r} + Cy^{n+2r} + Dy^{n+3r}$, &c. the terms of the series expressing $Ey^{m}x^{s}$ will consist of these dimensions of $y$, viz. $m + sn$, $m + sn + r$, $m + sn + 2r$, $m + sn + 3r$, &c. and by a like substitution in any other term as $Fy^{n}x^{t}$, the dimensions of $y$ will be $e + nk$, $e + nk + r$, $e + nk + 2r$, $e + nk + 3r$, &c. The former series of indices must coincide with the latter series, that the terms in which they are found may be compared together, and be found equal with opposite signs so as to destroy one another, and make the whole equation vanish.

The first series consists of terms arising by adding some multiple of $r$ to $m + sn$, the latter by adding some multiple of $r$ to $e + nk$; and that these may coincide, some multiple of $r$ added to $m + sn$ must be equal to some other multiple of $r$ added to $e + nk$. From which it appears that the difference of $m + sn$ and $e + nk$ is always

a multiple of $r$; and consequently that $r$ is a divisor of the difference of dimensions of $y$ in the terms $Ey^{m}x^{s}$ and $Fy^{n}x^{t}$, supposing $x = Ay^{n}$. It follows therefore "that $r$ is a common divisor of the differences of the dimensions of $y$ in the terms of the equation, when you have substituted $Ay^{n}$ for $x$ in all the terms." And if $r$ be assumed equal to the *greatest* common divisor (excepting some cases afterward to be mentioned you will have the true form of a series for $x$. And now the dimensions $y^{n}$, $y^{n+r}$, $y^{n+2r}$, $y^{n+3r}$, &c. being known, there remains only, by calculation, to determine the general coefficients $A$, $B$, $C$, $D$, &c. in order to find the series $Ay^{n} + By^{n+r} + Cy^{n+2r} + Dy^{n+3r} +$ &c. $= x$.

§ 109. This leads us to Sir *Isaac Newton's second general method* of series; which consists in assuming a series with undetermined coefficients expressing $x$, as $Ay^{n} + By^{n+r} + Cy^{n+2r} +$ &c. where $A$, $B$, $C$, &c. are supposed as yet unknown, but $n$ and $r$ are discovered by what we have already demonstrated; and substituting this every where for $x$, you must suppose, in the new equation that arises, the sum of all the terms that involve the same dimension of $y$ to vanish, by which means you will obtain particular equations, the *first* of which will give $A$, the *second* $B$, the *third* $C$, &c. and these values being







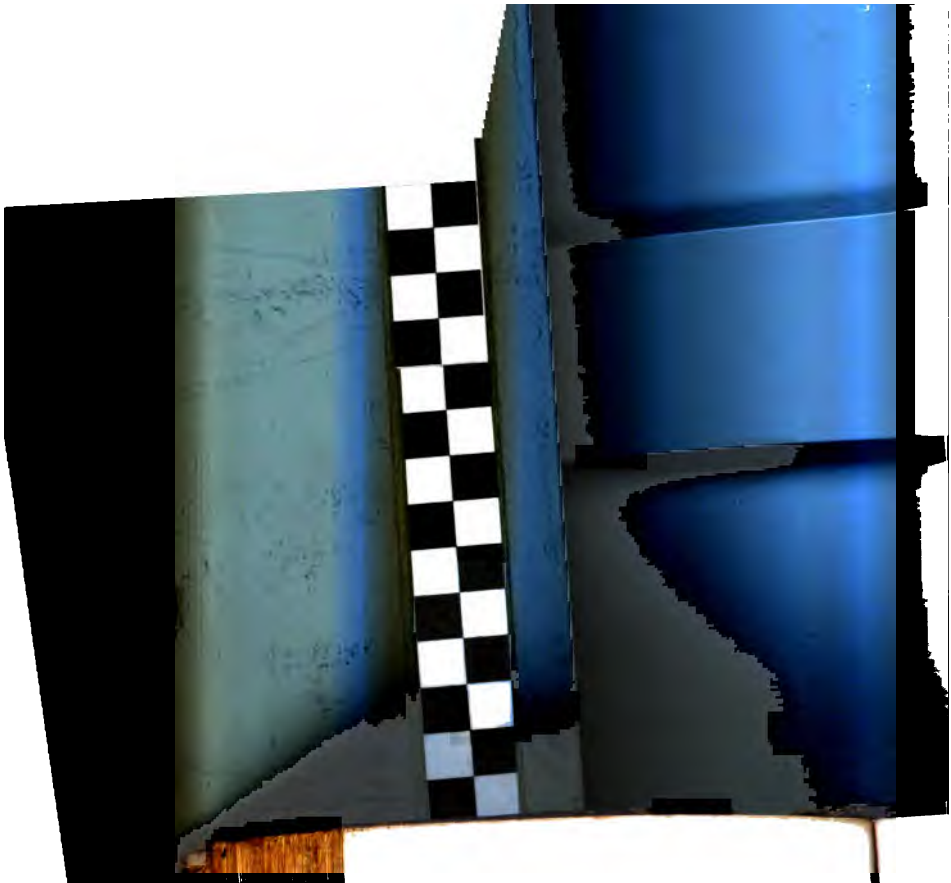
ıltiple of $r$; and conſequently that $r$ is
ır of the difference of dimenſions of $y$
rms $Ey^m x^n$ and $Fy^q x^s$, ſuppoſing $z = y$
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l equal to the *greateſt* common divi
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This leads us to Sir *Iſaac Newton*
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ion that ariſes, the ſum of all the
involve the ſame dimenſion of $y$
which means you will obtain partic
ns, the *firſt* of which will give $A$
$B$, the *third* $C$, &c. and theſe values
being ſubſtituted in the aſſumed ſeries for $A$, $B$, $C$, &c. the ſeries of $x$ will be obtained as far as you pleaſe.

Let us apply, for example, this method to the equation (of § 98) $x^3 + a^2x - 2a^3 + ayx - y^3 = 0$. Suppoſe it is required to find a ſeries converging the ſooner the leſs $y$ is: its firſt term (by § 99 or 102) is found to be $a$, ſo that $n = 0$. Subſtitute $a$ for $x$ in the equation, and the terms become $a^3 + a^3 - 2a^3 + a^3y - y^3$, and the differences of the indices are 0, 1, 2, 3; whoſe greateſt common meaſure is 1, ſo that $r = 1$. Aſſume therefore $x = A + By + Cy^2 + Dy^3$, &c. and ſubſtitute theſe ſeries for $x$ in the equation. Then

$$
\begin{aligned}
x^3 = {} & A^3 + 3A^2By + 3AB^2y^2 + B^3y^3 + \&c. \\
& + 3A^2Cy^2 + 3A^2Dy^3 + \&c. \\
& + 6ABCy^3 + \&c. \\
+ a^2x = {} & a^2A + a^2By + a^2Cy^2 + a^2Dy^3 + \&c. \\
+ ayx = {} & \quad aAy + aBy^2 + aDy^3 + \&c. \\
- 2a^3 = {} & - 2a^3 \\
- y^3 = {} & \ldots\ldots\ldots - 1 \times y^3.
\end{aligned}
$$

Now ſince $x^3 + a^2x + ayx - 2a^3 - y^3 = 0$, it follows that the ſum of theſe ſeries involving $y$ muſt vaniſh. But that cannot be if the coefficient of every particular term does not vaniſh. For every term where $y$ is infinitely little, is infinitely greater than the following terms, ſo that if





if every term does not vaniſh of itſelf, the addition or ſubtraction of the following terms which are infinitely leſs than it, or of the preceding terms which are infinitely greater, cannot deſtroy it; and therefore the whole cannot vaniſh. It appears therefore that $A^3 + a^2A - 2a^3 = 0$, is an equation for determining $A$, and gives $A = a$.

In order to determine $B$, you muſt ſuppoſe the ſum of the coefficients affecting $y$ to vaniſh, *viz.* $\overline{3A^2B + a^2B + aA} \times y = 0$, or, ſince $A = a$, $4a^2By + a^2y = 0$, and $B = -\frac{1}{4}$.

To determine $C$, in the ſame manner ſuppoſe $3AB^2y^2 + 3A^2Cy^2 + a^2Cy^2 + aBy^2 = 0$, or, ſubſtituting for $A$ and $B$ their values already found, $\frac{3a^2}{16} + 4a^2Cy^2 - \frac{ay^2}{4} = 0$, and conſequently $C = \frac{1}{64a}$. And, by proceeding in the ſame manner, $D = \frac{131}{512a^2}$, ſo that $x = a - \frac{1}{4}y + \frac{1}{64a}y^2 + \frac{131}{512a^2}y^3$, &c. as we found before in § 99.

§ 110. By this method you may transfer ſeries from one undetermined quantity to another, and obtain Theorems for the *reverſion* of ſeries.

Suppoſe that $x = ay + by^2 + cy^3 + dy^4 + \&c.$ and it is required to expreſs $y$ by a ſeries conſiſting of the powers of $x$. It is obvious that when

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infinitely less than it, or of the p
ns which are infinitely greater, co
it; and therefore the whole coeff
appears therefore that $A+\&c.$
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to determine $B$, you must suppos
he coefficients affecting $y$ to vanish,
$-a^2B+aA\times y=0$, or, since $A=$
$=0$, and $B=-\frac{1}{4}$.

mine $C$, in the same manner by
$+3A^2Cy^2+a^2Cy^2+aby^2=0$, &
for $A$ and $B$ their values already
$+4a^2Cy^2-\frac{cy^2}{4}=0$, and conse
$\frac{1}{64a}$. And, by proceeding in the
$D=\frac{131}{512a^2}$, so that $x=\frac{1}{4}$
$\frac{21}{2a^2}y^4$, &c. as we found before in

this method you may transfer le
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$x=ay+by^2+cy^3+dy^4+\&c.$
red to express $y$ by a series con
powers of $x$. It is obvious that
when



when $x$ is very little, $y$ is also very little, and that in order to determine the first term of the series, you need only assume $x=ay$. And therefore $y=\frac{x}{a}$; so that $n=1$. By substituting $\frac{x}{a}$ for $y$, you find the dimensions of $x$ in the terms will be 1, 2, 3, 4, &c. so that $r=1$ also. You may therefore assume $y=Ax+Bx^2+Cx^3+Dx^4+\&c.$ And by the substitution of this value of $y$ you will find

$$\begin{array}{lllll} ay= & aAx & +aBx^2 & +aCx^3 & +\&c. \\ by^2= & & bA^2x^2 & +2bABx^3 & +\&c. \\ cy^3= & & & cA^3x^3 & +\&c. \\ \&c. & & & \&c. & \end{array}$$

But the first term being already found to be $\frac{x}{2}$, you have $A=\frac{1}{a}$; and since $aB+bA^2=0$, it follows that $B=-\frac{b}{a^3}$. After the same manner you will find $C=\frac{2b^2-ac}{a^5}$. Whence $y=\frac{x}{a}-\frac{b}{a^3}x^2+\frac{2b^2-ac}{a^5}x^3+\&c.$

§ 111. Suppose again you have $ax+bx^2+cx^3+dx^4+\&c.=gy+by^2+iy^3+ky^4$, &c. to find $x$ in terms of $y$. You will easily see, by § 103, that the first term of the series for $x$ is $\frac{y}{a}$, that $n=1, r=1$. Therefore assume $x=Ay+By^2+Cy^3$, &c. and by substituting

this value for $x$ and bringing all the terms to one ſide, you will have

$$\begin{array}{lllll} ax = aAy + aBy^2 + & aCy^3 & + \&c. \\ bx^2 = & bA^2y^2 + 2bABy^3 & + \&c. \\ cx^3 = & & cA^3y^3 + \&c. \\ \&c. & & \&c. \end{array}$$

$$\begin{array}{l} -gy = -gy \\ -by^2 = \ldots\ldots -by^2 \\ -iy^3 = \ldots\ldots\ldots\ldots -iy^3 \\ \&c. \qquad\qquad\qquad\qquad \&c. \end{array}$$

From whence we ſee, firſt, that $aA = g$, and $A = \frac{g}{a}$. 2°. That $aB + bA^2 - b = 0$, and $B = \frac{b}{a} - \frac{bg^2}{a^3}$. 3°. That $aC + 2bAB + cA^3 - i = 0$, and therefore $C = \frac{i - 2bAB - cA^3}{a}$. And thus the the firſt terms of the ſeries $Ay + By^2 + Cy^3$, &c. are known*.

§ 112. Before we conclude it remains to clear a difficulty in this method that has embarraſſed ſome late ingenious writers, concerning "the value of $r$ to be aſſumed when *two* or *more* of the values of the firſt term of a ſeries for expreſſing $x$ are found equal;" a correction of the preceding Rule being neceſſary in that caſe. And the author of that correction having only collected it from experience, and given it us

* See Mr. *De Moivre*, in *Phil. Tranſ.* 240.

with

for $x$ and bringing all the terms
ou will have

$$aAy + aBy^2 + aCy^3 + \&c.$$
$$bA^2y^2 + 2bABy^3 + \&c.$$
$$cAy^3 + \&c.$$
$$\&c.$$

$$-g$$
$$\ldots\ldots -by^2$$
$$\ldots\ldots\ldots -fy^3$$
$$\&c.$$

e we see, first, that $aA=g$, and
. That $aB + bA^2 - b = 0$, and

3°. That $aC+2bAB+cA^3-i=0$,

$C = \frac{i-2bAB-cA^3}{a}$. And thus the
of the series $Ay+By^2+Cy^3$, &c.

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*Moivre*, in *Phil. Trans.* 240.

with



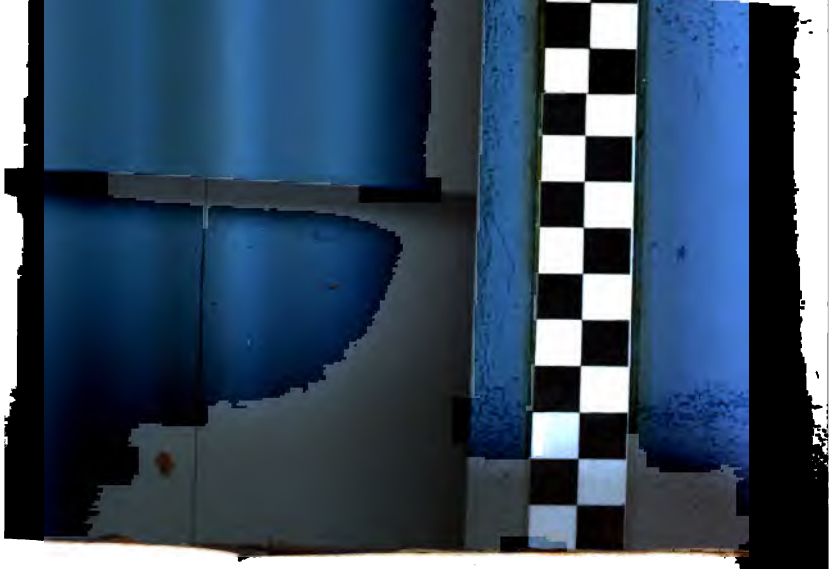
without proof, it is the more necessary to demonstrate it here.

It is to be observed then, that in order that the series $Ay^n + By^{n+r} + Cy^{n+2r} + Dy^{n+3r} + \&c.$ may express $x$, it is not only necessary that when it is substituted for $x$ in the proposed equation $Dy^l + Ey^m x^s + Fy^r x^t = 0$, the indices $m+ns$, $m+ns+r$, $m+ns+2r$, &c. should fall in with the indices $e+nk$, $e+nk+r$, $e+nk+2r$, &c. in order that the terms may be compared together to determine the coefficients $A$, $B$, $C$, &c. but it is also necessary, that in the particular equations for determining any of those coefficients, as $B$ for example, those terms that involve $B$ should not destroy each other. Thus the equation $3A^2B - 3A^2B - aA = 0$ can never determine $B$, because $3A^2B - 3A^2B = 0$, and thus $B$ exterminates itself out of the equation; besides the contradiction arising from $-A = 0$, when $A$ perhaps has been determined already to be equal to some real quantity.

In order to know how to evite this absurdity, let us suppose that the first order of terms in the proposed equation are, as before, $Dy^l$, $Ey^m x^s$, &c. and if $Ay^n$ is found to be the first term of a series for $x$, then the dimensions of $y$ in the first order of terms, arising by substituting in them $Ay^n$ for $x$, will be $m+ns$, and the dimensions of $y$ arising by substituting

$Ay^n + By^{n+r} + Cy^{n+2r}$, &c. for $x$ will be $m + ns$, $m + ns + r$, $m + ns + 2r$, &c. Suppose that $Fy^e x^k$ is the next order of terms, and, by the same substitution, the dimensions of $y$ arising from it will be

(because $Fy^e x^k = Fy^e \times \overline{Ay^n + By^{n+r} + Cy^{n+2r} + \&c.}^k$ $= FA^k y^{nk} + kFBA^{k-1} y^{nk+r}$, &c.) $e + nk$, $e + nk + r$, $e + nk + 2r$, &c. Now it is plain that $e + nk$ must coincide with some of the dimensions $m + ns$, $m + ns + r$, $m + ns + 2r$, &c. that the terms involving them may be compared together. And therefore, as we observed in § 108, $r$ must be the difference of $e + nk$ and $m + ns$, or some divisor of that difference. *In general*, $r$ must be assumed such a divisor of that difference as may allow not only $e + nk$ to coincide with some one of the series $m + ns$, $m + ns + r$, $m + ns + 2r$, &c. but as may make all the indices of the other orders besides $e + nk$ likewise to coincide with one of that series: that is, if $Gy/x^b$ is another term in the equation, $r$ must be so assumed that the series $f + nb$, $f + nb + r$, $f + nb + 2r$, &c. arising by substituting in it $Ay^n + By^{n+r} + Cy^{n+2r}$, &c. for $x$, may coincide somewhere with the first series $m + ns$, $m + ns + r$, $m + ns + 2r$, &c. And therefore we said, in § 108, "that $r$ must be assumed so as to be equal to some common divisor of the differences of the indices $m + ns$, $e + nk$, $f + nb$, which arise in the proposed equation by





$+r + Cy^{n+2r}$, &c. for $x$ will be $m+$
$m + ns + 2r$, &c. Suppoſe that $fy$
t order of terms, and, by the laſt
), the dimenſions of $y$ ariſing fro

$x^k = Fy^e \times \overline{Ay^n + By^{n+r} + Cy^{n+2r}}$ &c.
$+ kFBA^{k-1}y^{e+n+r}$, &c.) $e+n$
$e + nk + 2r$, &c. Now it is plai
muſt coincide with ſome of th
$n + ns$, $m + ns + r$, $m + ns + 2r$, &c.
ns involving them may be compar
And therefore, as we obſerved
iſt be the difference of $e+n$
me diviſor of that difference.
t be aſſumed ſuch a diviſor of th
may allow not only $e + nk$ to
ſome one of the ſeries $m+n$
$+ ns + 2r$, &c. but as may eaſi
s of the other orders beſides $e+n$
oincide with one of that ſeries
$fx^b$ is another term in the equa
e ſo aſſumed that the ſeries $f+$
$+ nb + 2r$, &c. ariſing by ſub
$fy^n + By^{n+r} + Cy^{n+2r}$, &c. for
ſomewhere with the firſt ſeries
$+ r$, $m + ns + 2r$, &c. And
d, in § 108, "that $r$ muſt be ſu
e equal to ſome common diviſor
es of the indices $m+ns$, $e+nk$,
ariſe in the propoſed equation
by



by ſubſtituting in it for $x$ the firſt term already known $Ay^n$." For by aſſuming $r$ equal to a common diviſor of the differences, the three ſeries

$m+ns$, $m+ns+r$, $m+ns+2r$, $m+ns+3r$, &c.
$e+nk$, $e+nk+r$, $e+nk+2r$, $e+nk+3r$, &c.
$f+nb$, $f+nb+r$, $f+nb+2r$, $f+nb+3r$, &c.

will coincide with one another, ſince ſome multiples of $r$ added to $m+ns$ will give $e+nk$ and all that follow it in the *ſecond* ſeries, and ſome multiples of $r$ added to $m+ns$ will alſo give $f+nb$ and all that follow it in the *third* ſeries. It is alſo obvious, that, if no particular reaſon hinder it, $r$ ought to be aſſumed equal to the *greateſt* common meaſure of theſe differences. For example, if the indices $m+ns$, $e+nk$, $f+nb$, happen to be arithmetical progreſſion, then $r$ ought to be aſſumed equal to the common difference of the terms, and the firſt of the ſecond ſeries will coincide with the ſecond of the firſt, and the firſt of the third ſeries will coincide with the ſecond of the ſecond ſeries, and with the third of the firſt, and ſo on.

§ 113. Theſe things being well underſtood, we are next to obſerve that after you have ſubſtituted $Ay^n + By^{n+r} + Cy^{n+2r}$, &c. for $x$ in the firſt order of terms in the equation, the terms that involve $m+ns$ dimenſions of $y$ will deſtroy one another; for $x - Ay^n$ muſt be a diviſor of the

the aggregate of theſe terms, ſince they give $Ay^n$ as one value of $x$: let $\overline{x - Ay^n} \times P$ repreſent that aggregate, and, ſubſtituting for $x$ its value $Ay^n + By^{n+r} + Cy^{n+2r}$, &c. that aggregate becomes $\overline{Ay^n + By^{n+r} + Cy^{n+2r}, \text{ &c.} - Ay^n} \times P = \overline{By^{n+r} + Cy^{n+2r}, \text{ &c.}} \times P$. Now the loweſt dimenſion in $\overline{x - Ay^n} \times P$ was ſuppoſed to be $m + ns$, whence the dimenſion of $P$, in the ſame terms, will be $m + ns - n$, and the loweſt dimenſion in $\overline{By^{n+r} + Cy^{n+2r} + \text{&c.}} \times P$ will be $n + r + m + ns - n = m + ns + r$. Suppoſe again that two values of $x$, determined from the firſt order of terms, are equal, and then $\overline{x - Ay^n}^2$ will be a diviſor of that aggregate of the firſt order of terms. Suppoſe that aggregate now $\overline{x - Ay^n}^2 \times P$, which by ſubſtitution of $Ay^n + By^{n+r} + Cy^{n+2r}$, &c. for $x$ will become $\overline{By^{n+r} + Cy^{n+2r} + \text{&c.}}^2 \times P$, in which the loweſt term will now be of $m + ns$ dimenſions, ſince in $\overline{x - Ay^n}^2 \times P$ the loweſt term is ſuppoſed of $m + ns$ dimenſions; and conſequently, in theſe terms, the dimenſion of $P$ itſelf is $m + ns - 2n$.

*In general*, if the number of values of $x$ ſuppoſed equal to $Ay^n$ be $p$, then muſt $\overline{x - Ay^n}^p$ be a diviſor of the aggregate of the terms of the firſt order. And that aggregate being expreſſed by $\overline{x - Ay^n}^p \times P$, in the loweſt terms, the dimenſions





gate of these terms, since they gi
value of $x$: let $\overline{x-Ay^{\alpha}}^{p} \times P$ represe
gate, and, substituting for $x$ its valu
$+r+Cy^{\alpha+2r}$, &c. that aggregate b
$\overline{+By^{\alpha+r}+Cy^{\alpha+2r}}$, &c. $-Ay^{\alpha}$
$-Cy^{\alpha+2r}$, &c. $\times P$. Now the lowe
in $\overline{x-Ay^{\alpha}} \times P$ was supposed to
ience the dimension of $P$, in the ter
be $m+ns-n$, and the lowest dim
$\overline{+r+Cy^{\alpha+2r}+}$ &c. $\times P$ will be $=$
$n=m+ns+r$. Suppose again its
of $x$, determined from the first ter
re equal, and then $\overline{x-Ay^{\alpha}}^{p}$ will
that aggregate of the first order
ose that aggregate now $\overline{x-Ay^{\alpha}}^{p}$
stitution of $Ay^{\alpha}+By^{\alpha+r}+Cy^{\alpha+2r}$
ecome $\overline{By^{\alpha+r}+Cy^{\alpha+2r}+\&c.}^{p}$
e lowest term will now be of $n+$
since in $\overline{x-Ay^{\alpha}}^{p} \times P$ the lowe
posed of $m+ns$ dimensions; an
, in these terms, the dimension
$+ns-2n$.

if the number of values of $x$ sig
o $Ay^{\alpha}$ be $p$, then must $\overline{x-Ay^{\alpha}}^{p}$ be
e aggregate of the terms of the first
that aggregate being expressed by
, in the lowest terms, the dimen-
sions



sions of $y$ in $P$ will be $m+ns-pn$, that in $\overline{x-Ay^{\alpha}}^{p}$ they may be $m+ns$, as we always suppose. Substitute in $\overline{x-Ay^{\alpha}}^{p} \times P$ for $x-Ay^{\alpha}$ its value $By^{\alpha+r}+Cy^{\alpha+2r}+$ &c. and in the result $\overline{By^{\alpha+r}+Cy^{\alpha+2r}+\&c.}^{p} \times P$ the lowest dimensions of $y$ will be $pn+pr+m+ns-pn = m+ns+pr$.

§ 114. From what has been said we conclude that when you have substituted for $x$ in the first order of terms of the equation proposed the series $Ay^{\alpha}+By^{\alpha+r}+Cy^{\alpha+2r}+$ &c. the first term of which $Ay^{\alpha}$ is known, and the values of $x$ whose number is $p$ are found equal, then the terms arising that involve $m+ns$, $m+ns+r$, $m+ns+2r$, &c. till you come to $m+ns+pr$, will destroy each other and vanish; so that the first term with which the terms of the second order $e+nk$ can be compared must be that which involves $m+ns+pr$; and therefore supposing $e+nk=m+ns+pr$, or $r=\frac{e+nk-m-ns}{p}$ "the highest value you can give $r$ must be the difference of $e+nk$ and $m+ns$ divided by $p$ the number of equal values of the first term of the series." If this value of $r$ is a common measure of all the differences of the indices, then is it a just value of $r$; but if it is not, such a value of $r$ must be assumed, as may measure this and all the differences: that is, "such a value as may

be the greateſt common meaſure of the leaſt difference divided by $p$ (*viz.* $\frac{e+nk-m-ns}{p}$) and of the common meaſure of all the differences." For thus the indices $m+ns$, $m+ns+r$, $m+ns+2r$, &c. will coincide with $e+nk$, $e+nk+r$, $e+nk+2r$, &c. and with $f+nb$, $f+nb+r$, $f+nb+2r$, &c. and you ſhall always have terms to be compared together ſufficient to determine $B$, $C$, $D$, &c. the general coefficients of the ſeries aſſumed for $x$.

§ 115. To all this it may be added, that if $x-Ay^n$ be a diviſor of the aggregate of the terms of the *ſecond* order $Fy^tx^t$, &c. then, by ſubſtituting for $x$ the ſeries $Ay^n+By^{n+r}+Cy^{n+2r}$ + &c. there vaniſh not only as many terms of the ſeries involving $m+ns$, $m+ns+r$, $m+ns+2r$, &c. as there are equal values of the firſt term $Ay^n$; but the terms involving $e+nk$ dimenſions of $y$ vaniſh alſo; and therefore it is then only neceſſary that $e+nk+r$ coincide with $m+ns+pr$, ſo that, in that caſe, you need only take $r=\frac{e+nk-m-ns}{p-1}$. And if $\overline{x-Ay^n}^{p-1}$ be a diviſor of the aggregate of the ſecond order of terms, then the terms after ſubſtituting for $x$ the ſeries $Ay^n+By^{n+r}+Cy^{n+2r}$ &c.) which involve $e+nk$, $e+nk+r$, $e+nk+2r$, &c. will vaniſh to the term $e+nk+\overline{p-1}\times r$; ſo that, ſup-

ſuppoſing $e+nk+\overline{p-1}\times r=m+ns+pr$, you have $r=e+nk-m-ns$, that is, to the *leaſt* difference of the indices $m+ns$, $e+nk$, $f+nb$, &c. provided that difference be a meaſure of the other differences; although there may be as many values of the firſt term of the ſeries equal as there are units in $p$. Or, if that does not happen, $r$ muſt be taken, as formerly, equal to the greateſt common meaſure of the differences.

§ 116. Suppoſe that the orders of terms of the equation can be expreſſed the *firſt* by $\overline{x-Ay^n}|^p\times P$, the *ſecond* by $\overline{x-Ay^n}|^q\times Q$, the *third* by $\overline{x-Ay^n}|^r\times L$, &c. and ſuppoſe that $Ey^{n+s}$ is one of the firſt, $Fy^{n+s}$ one of the ſecond, $Gy^{n+s}$ one of the third, and ſo on: then it is plain that, ſubſtituting for $x$ the ſeries $Ay^n+By^{n+r}+Cy^{n+2r}$, &c. the loweſt term that will remain in the firſt will be $m+ns+pr$ dimenſions of $y$, the loweſt term that will remain in the ſecond will be of $e+nk+qr$, and the loweſt term remaining in the third of $f+nb+lr$ dimenſions of $y$. For by the ſame reaſoning as we uſed, in § 113, to demonſtrate that, in the firſt order of terms $\overline{x-Ay^n}|^p\times P$, the loweſt dimenſions of $y$ are $m+ns+pr$, we ſhall find that, in the ſubſequent orders, the loweſt dimenſions of $y$ in the terms $\overline{x-Ay^n}|^q\times Q=\overline{By^{n+r}+Cy^{n+2r}\ \&c.}|^q\times Q$ muſt

## CHAP. XI.

### Of the Rules for finding the number of impoſſible Roots in an equation.

§ 117. THE number of *impoſſible* roots in an equation may, for moſt part, be found by this

### RULE.

"*Write down a ſeries of fractions whoſe denominators are the numbers in this progreſſion* 1, 2, 3, 4, 5, &c. *continued to the number which expreſſes the dimenſion of the equation. Divide every fraction in the ſeries by that which precedes it, and place the quotients in order over the middle terms of the equation. And if the ſquare of any term multiplied into the fraction that ſtands over it gives a product greater than the rectangle of the two adjacent terms, write under the term the ſign* +, *but if that product is not greater than the rectangle, write* −; *and the ſigns under the extreme terms being* +, *there will be as many imaginary roots as there are changes of the ſigns from* + *to* −, *and from* − *to* +.

Thus

## CHAP. XI.

### Rules for finding the num- of impoſſible Roots in a ion.

HE number of *impoſſible roots* an equation may, for moſt pa- this

### RULE.

*a ſeries of fractions whoſe deno- the numbers in this progreſſion* , &c. *continued to the number equ- be dimenſion of the equation. Th- fraction in the ſeries by that num- , and place the quotients in the middle terms of the equation. If are of any term multiplied into it at ſtands over it gives a produ the rectangle of the two adjacen under the term the ſign +, but if is not greater than the rectangle nd the ſigns under the extreme +, there will be as many inſta- as there are changes of the to —, and from — to +.*

Thus



Thus, the given equation being $x^3+px^2+3p^2x-q=0$, I divide the ſecond fraction of the ſeries $\frac{3}{1}, \frac{2}{2}, \frac{1}{3}$, by the firſt, and the third by the ſecond, and place the quotients $\frac{1}{3}$ and $\frac{1}{3}$ over the middle terms in this manner;

$$x^3+px^{\frac{1}{3}}+3p^2x^{\frac{1}{3}}-q=0.$$
$$+\quad -\quad +\quad +$$

Then becauſe the ſquare of the ſecond term multiplied into the fraction that ſtands over it, that is, $\frac{1}{3}\times p^2x^4$ is leſs than $3p^2x^4$ the rectangle under the firſt and third terms, I place under the ſecond term the ſign —; but as $\frac{1}{3}\times 9p^4x^2$ $(=3p^4x^2)$ the ſquare of the third term multiplied into its fraction is greater than *nothing*, and conſequently much greater than $-pqx^2$ the negative product of the adjoining terms, I write under the third term the ſign +. I write + likewiſe under $x^3$ and $-q$ the firſt and laſt terms, and finding in the ſigns thus marked two changes, one from + to —, and another from — to +, I conclude the equation has two impoſſible roots.

In like manner the equation $x^3-4x^2+4x-6=0$ has two impoſſible roots;

$$x^3-4x^{\frac{1}{1}}+4x^{\frac{1}{2}}-6=0;$$
$$+\quad +\quad -\quad +$$





and the equation $x^{10} - 6x^5 - 3x - 2 = 0$ the ſame number

$$\begin{array}{c} \frac{5}{5}\quad\frac{4}{5}\quad\frac{3}{5} \\ x^{10} - 6x^5 - 3x - 2 = 0. \\ ++\ +\ \ -\ \ + \end{array}$$

For the ſeries of fractions $\frac{4}{1}, \frac{3}{2}, \frac{2}{3}, \frac{1}{4}$ yields, by dividing them as the Rule directs, the fractions $\frac{3}{8}, \frac{4}{9}, \frac{3}{8}$ to be placed over the terms. Then the ſquare of the ſecond term, which is *nothing*, multiplied by the fraction over it being ſtill *nothing*, and yet greater than $-6x^6$ the negative product of the adjacent terms, I write under (•) the term that is wanting, the ſign +, and proceeding as in the former examples, I conclude, from the two changes that happen in the ſeries $++\,+\,-\,+$, that the equation has two of its roots impoſſible.

The ſame way we diſcover two impoſſible roots in the equation

$$\begin{array}{c} \frac{5}{5}\quad\frac{4}{5}\quad\frac{3}{5}\quad\frac{2}{5}\quad\frac{1}{5} \\ x^5 - 4x^4 + 4x^3 - 2x^2 - 5x - 4 = 0. \\ +\ \ +\ \ -\ \ +\ \ +\ \ + \end{array}$$

When two or more terms are wanting in the equation, under the firſt of ſuch terms place the ſign −, under the ſecond +, under the third −, and ſo on alternately; only when the two terms to the right and left of the deficient terms have

have contrary signs, you are always to write the sign + under the last deficient term.

As in the equations

$$x^5 + ax^4 * * * + a^5 = 0$$
$$+ \quad + - + - \quad +$$
$$\text{and } x^5 + ax^4 * * * - a^5 = 0$$
$$+ \quad + - + + \quad +$$

the first of which has *four* impossible roots, and the other *two*. Thus likewise the equation

$$x^7 - 2x^6 + 3x^5 - 2x^4 + x^3 * * - 3 = 0$$
$$+ \quad - \quad + \quad - \quad + - + \quad +$$

has *six* impossible roots.

Hence too we may discover if the imaginary roots lie hid among the affirmative, or among the negative roots. For the signs of the terms which stand over the signs below that change from + to − and − to +, shew, by the number of their variations, how many of the impossible roots are to be reckoned affirmative; and that there are as many negative imaginary roots as there are repetitions of the same sign. As in the equation

$$x^5 - 4x^4 + 4x^3 - 2x^2 - 5x - 4 = 0$$
$$+ \quad + \quad - \quad + \quad + \quad +$$

the signs (− + −) of the terms $-4x^4 + 4x^3 - 2x^2$ which stand over the signs + − + pointing

ing out two affirmative roots *, we infer that two impoſſible roots lie among the affirmative: and the three changes of the ſigns in the equation (+ − + − − −) giving three affirmative roots and two negative, the five roots will be one real affirmative, two negative, and two imaginary affirmatives. If the equation had been

$$x^5 - 4x^4 - 4x^3 - 2x^2 - 5x - 4 = 0,$$
$$+ \quad + \quad - \quad - \quad + \quad +$$

the terms $-4x^4 - 4x^3$ that ſtand over the firſt variation + −, ſhew, by the repetition of the ſign −, that one imaginary root is to be reckoned negative, and the terms $-2x^2 - 5x$ that ſtand over the laſt variation − +, give, for the ſame reaſon, another negative impoſſible root; ſo that the ſigns of the equation (+ − − − − −) giving one affirmative root, we conclude that of the four negative roots, two are imaginary.

This always holds good unleſs, which ſometimes may happen, there are more impoſſible roots in the equation than are diſcoverable by the Rule."

*This Rule hath been inveſtigated by ſeveral eminent Mathematicians in various ways; and others, ſimilar to it, invented and publiſhed* †. *But the*

* See § 19.

† See *Stirling*'s Lineae iij. Ord. *Newton*. p. 59. *Phil. Tranſ.* N° 394, 404, 408.

*original*

*original Rule being, on account of its ſimplicity and eaſy application, if not preferable to all others, at leaſt the fitteſt for this place, it is ſufficient to direct the Reader where he may find the ſubject more fully treated; and to add the demonſtration our Author has given of it towards the end of his Letter to Mr.* Folkes, Phil. Tranſ. N° 408, *as it depends only on what has been demonſtrated in* Chap. 5. *concerning the limits of the roots of equations.*

§ 118. Let $ax^2 \pm px \pm q = 0$ be any adfected quadratic equation; and, by § 88, *Part* I. its roots will be $\frac{1}{2a} \times \mp p \pm \sqrt{p^2 \mp 4aq}$: whence it is plain that, the ſign of $q$ in the given equation being $+$, the roots will be impoſſible as oft as $4aq$ is greater than $p^2$, or $\frac{1}{4}p^2$ leſs than $a \times q$.

§ 119. It was ſhewn, *in general* (§ 45—50) *that the roots of the equation* $x^n - Ax^{n-1} + Bx^{n-2} - Cx^{n-3}$ &c. $= 0$, *are the* limits *of the roots of the equation* $nx^{n-1} - \overline{n-1} \times Ax^{n-2} + \overline{n-2} \times Bx^{n-3}$ &c. $= 0$, *or of any equation that is deduced from it by multiplying its terms by any arithmetical progreſſion* $l \mp d$, $l \mp 2d$, $l \mp 3d$, &c. *and converſely the roots of this new equation will be the* limits *of the roots of the propoſed equation* $x^n - Ax^{n-1} + Bx^{n-2}$ &c. $= 0$.

And that *if any roots of the equation of the limits are impoſſible, there muſt be ſome roots of the propoſed equation impoſſible.*

§ 120. Let $x^3 - Ax^2 + Bx - C = 0$ be a cubic equation, and the *equation of limits* $3x^2 - 2Ax + B = 0$. If the two roots of this laſt are imaginary, there are two imaginary roots of the given equation $x^3 - Ax^2 + Bx - C = 0$, by the laſt *Art.* But, by the preceding *Art.* this happens as oft as $\frac{1}{3}A^2$ is leſs than $B$; and, in that caſe, the given equation has two imaginary roots.

Again, multiplying the terms of the equation by the terms of the progreſſion, $0, -1, -2, -3$, we get another *equation of the limits* $Ax^2 - 2Bx + 3C = 0$; whoſe two roots, and conſequently two roots of the given equation, are imaginary when $\frac{1}{4}B^2$ is leſs than $A \times C$.

Hence likewiſe the biquadratic $x^4 - Ax^3 + Bx^2 - Cx + D = 0$, will have two imaginary roots, if two roots of the equation $4x^3 - 3Ax^2 + 2Bx - C = 0$ be imaginary; or if two roots of the equation $Ax^3 - 2Bx^2 + 3Cx - 4D = 0$ be imaginary. But two roots of the equation $4x^3 - 3Ax^2 + 2Bx - C = 0$ muſt be imaginary, when two roots of the quadratic $6x^2 - 3Ax + B = 0$, or of the quadratic $3Ax^2 - 4Bx + 3C = 0$, are imaginary, becauſe the roots of theſe quadratic equations are the *limits* of the roots of that cubic, and for the ſame reaſon two roots of the cubic equation $Ax^3 - 2Bx^2 + 3Cx - 4D = 0$ muſt be imaginary, when the roots of the quadratic $3Ax^2 - 4Bx + 3C = 0$, or

1. Let $x^3 - Ax^2 + Bx - C = 0$ b
quation, and the *equation of in*
$Ax + B = 0$. If the two roots of t
naginary, there are two imaginary ro
iven equation $x^3 - Ax^2 + Bx - C =$
ft *Art.* But, by the preceding
ens as oft as $\frac{1}{3}A^2$ is leſs than $B$;
ſe, the given equation has two ima

multiplying the terms of the equ
e terms of the progreſſion, 0, -
we get another *equation of the* le
$+ 3C = 0$; whoſe two roots, a
ly two roots of the given equati
ary when $\frac{4}{9}B^2$ is leſs than $AC$.
kewiſe the biquadratic $x^4 - B$
$D = 0$, will have two imagin
vo roots of the equation $4x^3 - 3$
$= 0$ be imaginary; or if two ro
ation $Ax^3 - 2Bx^2 + 3Cx - 4D =$
y. But two roots of the equati
$+ 2Bx - C = 0$ muſt be imag
two roots of the quadratic $\frac{1}{3}$
, or of the quadratic $\frac{1}{3}Ax^2 - 2$
e imaginary, becauſe the roots
ic equations are the *limits* of the
cubic, and for the ſame reaſo
he cubic equation $Ax^3 - 2Bx^2 +$
, muſt be imaginary, when the
quadratic $3Ax^2 - 4Bx + 3C = 0$
or of the quadratic $Bx^2 - 3Cx + 6D = 0$ are impoſſible. Therefore two roots of the biquadratic $x^4 - Ax^3 + Bx^2 - Cx + D = 0$ muſt be imaginary when the roots of any one of theſe three quadratic equations $6x^2 - 3Ax + B = 0$, $\frac{3}{4}Ax^2 - 4Bx + 3C = 0$, $Bx^2 - 3Cx + 6D = 0$ become imaginary; that is, when $\frac{3}{4}A^2$ is leſs than $B$, $\frac{4}{9}B^2$ leſs than $AC$, or $\frac{1}{4}C^2$ leſs than $BD$.

§ 121. By proceeding in the ſame manner, you may deduce from any equation $x^n - Ax^{n-1} + Bx^{n-2} - Cx^{n-3}$ &c. $= 0$, as many quadratic equations as there are terms excepting the firſt and laſt, whoſe roots muſt be all real quantities, if the propoſed equation has no imaginary roots. The quadratic deduced from the three firſt terms $x^n - Ax^{n-1} + Bx^{n-2}$ will manifeſtly have this form, $n \times \overline{n-1} \times \overline{n-2} \times \overline{n-3}$ &c. $\times x^{n-4} - \overline{n-1} \times \overline{n-2} \times \overline{n-3} \times \overline{n-4}$ &c. $\times Ax + \overline{n-2} \times \overline{n-3} \times \overline{n-4} \times \overline{n-5}$ &c. $\times B = 0$, continuing the factors in each till you have as many as there are units in $n-2$. Then dividing the equation by all the factors $n-2$, $n-3$, $n-4$, &c. which are found in each coefficient, the equation will become $n \times \overline{n-1} \times x^2 - \overline{n-1} \times 2Ax + 2 \times 1 \times B = 0$, whoſe roots will be imaginary, by § 118, when $n \times \overline{n-1} \times 2 \times 4B$ exceeds $\overline{n-1}^2 \times 4A^2$, or when $B$ exceeds $\frac{n-1}{2n}A^2$: ſo that the propoſed equation muſt

have some imaginary roots when $B$ exceeds $\frac{n-1}{2n}A^2$. The quadratic equation deduced in the same manner from the three first terms of the equation $Ax^{n-1} - 2Bx^{n-2} + 3Cx^{n-3}$ &c. $= 0$, will have this form, $\overline{n-1} \times \overline{n-2} \times \overline{n-3}$ &c. $\times Ax^2 - \overline{n-2} \times \overline{n-3} \times \overline{n-4}$ &c. $\times 2Bx + \overline{n-3} \times \overline{n-4} \times \overline{n-5}$ &c. $\times 3C = 0$, which dividing by the factors common to all the terms, is reduced to $\overline{n-1} \times \overline{n-2} \times Ax^2 - \overline{n-2} \times 4Bx + 6C = 0$, whose roots must be imaginary when $\frac{2}{3} \times \frac{n-2}{n-1} \times B^2$ is less than $AC$; and therefore in that case some roots of the proposed equation must be imaginary.

§ 122. In general, let $Dx^{n-r+1} - Ex^{n-r} + Fx^{n-r-1}$ be any three terms of the equation, $x^n - Ax^{n-1} + Bx^{n-2}$ &c. $= 0$, that immediately follow one another; multiply the terms of this equation first by the progression $n$, $n-1$, $n-2$, &c. then by the progression $n-1$, $n-2$, $n-3$, &c. then by $n-2$, $n-3$, $n-4$, &c. till you have multiplied by as many progressions as there are units in $n-r-1$: then multiply the terms of the equation that arises, as often by the progression 0, 1, 2, 3, &c. as there are units in $r-1$, and you will at length arrive at a quadratic of this form;

$\overline{n-r+1} \times \overline{n-r} \times \overline{n-r-1} \times \overline{n-r-2}$ &c. $\times \overline{r-1} \times \overline{r-2} \times \overline{r-3} \times \overline{r-4}$ &c. $\times Dx^2$ —

$\overline{n-r} \times \overline{n-r-1} \times \overline{n-r-2} \times \overline{n-r-3}$ &c. $\times r \times \overline{r-1} \times \overline{r-2} \times \overline{r-3}$ &c. $\times Ex + \overline{n-r-1} \times \overline{n-r-2} \times \overline{n-r-3} \times \overline{n-r-4}$ &c. $\times \overline{r+1} \times r \times \overline{r-1} \times \overline{r-2}$ &c. $\times F = 0$: and dividing by the factors $n-r-1$, $n-r-2$, &c. and $r-1$, $r-2$, &c. which are found in each coefficient, this equation will be reduced to $\overline{n-r+1} \times \overline{n-r} \times 2 \times 1 \times Dx^2 - \overline{n-r} \times 2 \times r \times 2Ex + 2 \times 1 \times \overline{r+1} \times rF = 0$, whose roots must be imaginary, by § 118, when $\frac{n-r}{n-r+1} \times \frac{r}{r+1} \times E^2$ is less than $DF$. From which it is manifest, that if you divide each term of this series of fractions $\frac{n}{1}$, $\frac{n-1}{2}$, $\frac{n-2}{3}$, $\frac{n-3}{4}$, &c. $\frac{n-r+1}{r}$, $\frac{n-r}{r+1}$, by that which precedes it, and place the quotients above the terms of the equation $x^n - Ax^{n-1} + Bx^{n-2} - Cx^{n-3}$ &c. $= 0$, beginning with the second: then if the square of any term multiplied by the fraction over it be found less than the product of the adjacent terms, some of the roots of that equation must be imaginary quantities.

§ 123. An equation may have impossible roots although none are discovered by the Rule: because, "though *real* roots in the *given equation* always give *real* roots in the *equation of limits*; yet it does not follow, *conversely*, that when the roots of the *equation of limits* are real, those of

of the equation from which it is produced must be such likewise. Thus the *cubic*

$$\left.\begin{matrix} x^3 - 2m \\ -q \end{matrix}\right\} \times x^2 \left.\begin{matrix} +m^2 \\ +2qm \\ +n \end{matrix}\right\} \times x - q \times \overline{m^2 + n} = 0,$$

has two of its roots imaginary, $m + \sqrt{-n}$, $m - \sqrt{-n}$, the third being $+q$: and yet in the *equation of limits* $3x^2 - \overline{4m + 2q} \times x^2 + m^2 + 2qm + m = 0$, if $\overline{m - q}^2$ exceeds $3n$, the roots of the equation of limits will be real. Or if the other equation of limits $\overline{2m + q} \times x^3 - 2 \times \overline{m^2 + 2qm + n} \times x + 3q \times \overline{m^2 + n} = 0$ is found by multiplying by the progression $0, -1, -2, -3$; it will have its roots real as oft as $\overline{m^2 + 2qm + n}^2$ exceeds $\overline{2m + q} \times 3q \times \overline{m^2 + n}$. And the like may be shewn of higher equations.

§ 124. The reason why this Rule, and perhaps every other that depends on the comparison of the square of a term with the rectangles of the terms on either side of it, must sometimes fail to discover the impossible roots, may appear likewise from this consideration; that the number of such comparisons being always less by *unit* than the number of the quantities $q$, $m$, $n$, &c. in the general equation; they cannot include and fix the relations of these quantities,

on

on which the ratio of *greater* or *leſſer* inequality of the ſquares and rectangles depends; no more than equations fewer in number than the quantities ſought can furniſh a determinate ſolution of a problem.

## CHAP. XII.

### Containing a general demonſtration of Sir *Iſaac Newton*'s Rule for finding the ſums of the powers of the roots of an equation *.

LET the equation be $\overline{x-a} \times \overline{x-b} \times \overline{x-c} \times \overline{x-d} \times$ &c. $= 0$, or,

$$\left.\begin{array}{l} x^n - Ax^{n-1} + Bx^{n-2} - Cx^{n-3} \ldots \\ \ldots - Ix^1 + Kx^2 - Lx + M \end{array}\right\} = 0.$$

It is known that $A = a + b + c + d +$ &c. $B = ab + ac + ad + bc + bd + cd +$ &c. $C = abc + abd + bcd +$ &c. $D = abcd +$ &c. the *parts* or *terms* of the coefficients $A$, $B$, $C$, $D$, &c. being of 1, 2, 3, 4, *&c. dimenſions*; that is, containing as many *roots* or *factors* as there are terms of the equation preceding them, reſpectively.

* See *Arith. Univerſ.* pag. 157. And *Chap.* II. § 15—17, of this *Part*.

CASE

## CASE I.

Let $r$ be an *index equal* to $n$, or *greater* than $n$, then, multiplying the equation by $x^{r-n}$, and ſubſtituting ſucceſſively $a$, $b$, $c$, $d$, &c. for $x$, you obtain

$$\left.\begin{array}{l} a^r - Aa^{r-1} + Ba^{r-2} - Ca^{r-3} \ldots \\ \ldots - La^{r-n+1} + Ma^{r-n} \end{array}\right\} = 0,$$
$$\left.\begin{array}{l} b^r - Ab^{r-1} + Bb^{r-2} - Cb^{r-3} \ldots \\ \ldots - Lb^{r-n+1} + Mb^{r-n} \end{array}\right\} = 0,$$
$$\left.\begin{array}{l} c^r - Ac^{r-1} + Bc^{r-2} - Cc^{r-3} \ldots \\ \ldots - Lc^{r-n+1} + Mc^{r-n} \end{array}\right\} = 0,$$
&c.

Whence, by tranſpoſition and addition, this *Theorem* reſults, that, in this caſe, "the ſum of the powers of the roots, of the exponent $r$, is equal to the ſum of their powers of the exponent $r-1$ multiplied by $A$, *minus* the ſum of their powers of the exponent $r-2$ multiplied by $B$, + the ſum of thoſe of the exponent $r-3$ multiplied by $C$, and ſo on."

It remains to find the ſums of the powers of the roots, when the exponents are *leſs* than $n$ the exponent of the equation,

## CASE II.

If $r$ is leſs than $n$, and $H$ be the coefficient in the equation, of the *dimenſions* $r$; that is, if $H$ be taken ſo that the number of terms preceding it in the equation be equal to $r$, or the num-

ber

CASE I.

*index equal* to *n*, or *greater* than

olying the equation by $x^{n-1}$, and

ceſſively *a*, *b*, *c*, *d*, &c. for *x*,

$$\left.\begin{array}{l} + Ba^{r-2} - Ca^{r-3} \ldots \\ {}^{n+1} + Ma^{r-n} \end{array}\right\} = 0$$

$$\left.\begin{array}{l} - Bb^{r-2} - Cb^{r-3} \ldots \\ {}^{r+1} + Mb^{r-n} \end{array}\right\} = 0$$

$$\left.\begin{array}{l} Bc^{r-2} - Cc^{r-3} \ldots \\ {}^{+1} + Mc^{r-n} \end{array}\right\} = 0$$

ıfpoſition and addition, thi

ıat, in this caſe, "the ſu

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ım of thoſe of the exponen

*C*, *and ſo on.*"

the ſums of the powers o

exponents are *leſs* than

quation,

S E II.

ınd *H* be the coefficient

e *dimenſions* $r$; that is, if

ıumber of terms preced

equal to $r$, or the num-

ber



ber of *factors* in its parts *abcdefgk*, *abcdefgi*, &c, equal to $r$, then the Theorem may be expreſſed in the following manner.

$$a^r + b^r + c^r + d^r + \&c.$$

$$= \left\{\begin{array}{l} +a^{r-1} \\ +b^{r-1} \\ +c^{r-1} \\ +d^{r-1} \\ +\&c. \end{array}\right\} \times A - \left\{\begin{array}{l} a^{r-2} \\ b^{r-2} \\ c^{r-2} \\ d^{r-2} \\ \&c. \end{array}\right\} \times B + \left\{\begin{array}{l} +a^{r-3} \\ +b^{r-3} \\ +c^{r-3} \\ +d^{r-3} \\ +\&c. \end{array}\right\} \times C \ldots$$

$$\ldots\ldots\ldots\ldots\ldots\ldots - r \times H.$$

The caſe when $r = n-1$ is eaſily demonſtrated; for, dividing the equation by $x$, we have

$$x^{n-1} - Ax^{n-2} + Bx^{n-3} \ldots - L + \frac{M}{x} = 0.$$

Whence

$$a^{n-1} - Aa^{n-2} + Ba^{n-3} \ldots - L + \frac{M}{a} = 0,$$

$$b^{n-1} - Ab^{n-2} + Bb^{n-3} \ldots - L + \frac{M}{b} = 0,$$

$$c^{n-1} - Ac^{n-2} + Bc^{n-3} \ldots - L + \frac{M}{c} = 0,$$

&c. &c.

and (becauſe $L = \frac{M}{a} + \frac{M}{b} + \frac{M}{c} + \frac{M}{d} + \&c.$) we ſhall have $a^{n-1} + b^{n-1} + c^{n-1} + \&c.$

$$= \left\{\begin{array}{l} +a^{n-2} \\ +b^{n-2} \\ +c^{n-2} \\ +\&c. \end{array}\right\} \times A - \left\{\begin{array}{l} a^{n-3} \\ b^{n-3} \\ c^{n-3} \\ \&c. \end{array}\right\} \times B + \left\{\begin{array}{l} +a^{n-4} \\ +b^{n-4} \\ +c^{n-4} \\ +\&c. \end{array}\right\} \times C \ldots$$

$$\ldots\ldots\ldots\ldots + n-1 \times L.$$

When

When $r = n - 2$, the demonſtration is derived from hence, that $\overline{a^2 + b^2 + c^2 + d^2 + \&c.} = A^2 - 2B$ (*pag.* 142.) as follows.

By § 32. transform the given equation, *viz.* $\left.\begin{array}{l} x^n - Ax^{n-1} + Bx^{n-2} - Cx^{n-3} \ldots \\ \ldots - Ix^1 + Kx^2 - Lx + M \end{array}\right\} = 0$ into the equation

$$\left.\begin{array}{l} z^n - \frac{L}{M} z^{n-1} + \frac{K}{M} z^{n-2} - \frac{I}{M} z^{n-3} \ldots \\ \ldots - \frac{C}{M} z^3 + \frac{B}{M} z^2 - \frac{A}{M} z + \frac{1}{M} \end{array}\right\} = 0;$$

the roots $\alpha$, $\beta$, $\gamma$, $\delta$, &c. of which new equation ſhall be reſpectively equal to the reciprocals $\frac{1}{a}$, $\frac{1}{b}$, $\frac{1}{c}$, $\frac{1}{d}$, &c. of the roots of the original equation.

Divide now the original equation by $x^2$, and in the quotient ſubſtitute for $x$ the roots $a$, $b$, $c$, $d$, &c. ſucceſſively, ſo you ſhall have

$$\left.\begin{array}{l} a^{n-2} - Aa^{n-3} + Ba^{n-4} - Ca^{n-5} \ldots \\ \ldots - Ia + K - \frac{L}{a} + \frac{M}{a^2} \end{array}\right\} = 0,$$

$$\left.\begin{array}{l} b^{n-2} - Ab^{n-3} + Bb^{n-4} - Cb^{n-5} \ldots \\ \ldots - Ib + K - \frac{L}{b} + \frac{M}{b^2} \end{array}\right\} = 0,$$

$$\left.\begin{array}{l} c^{n-2} - Ac^{n-3} + Bc^{n-4} - Cc^{n-5} \ldots \\ \ldots - Ic + K - \frac{L}{c} + \frac{M}{c^2} \end{array}\right\} = 0,$$

&c.

Add all theſe equations together, and for $n - 2$ ſubſtitute its value $r$, and it will be

*ar*

$r = n - 2$, the demonſtration is ob
hence, that $\overline{a^2 + b^2 + c^2 + \&c.}$
(*pag.* 142.) as follows.
transform the given equation, viz
$r + Bx^{n-2} - Cx^{n-3} \ldots \Big\} = 0$ an
$Kx^2 - Lx + M$

$^2 + \frac{K}{M}z^{n-2} - \frac{I}{M}z^{n-3} \ldots \Big\} =$
$\cdot \frac{B}{M}z^2 - \frac{A}{M}z + \frac{1}{M} \Big\}$
$\gamma$, &c. of which new equ
eſpectively equal to the recipr
$\frac{1}{a}$, &c. of the roots of th

2.

ıe original equation by $x^r$, and
ſubſtitute for $x$ the roots $\frac{1}{a}$,
ely, ſo you ſhall have
$\cdot Ba^{n-4} - Ca^{n-5} \ldots \Big\} =$
$- \frac{L}{a} + \frac{M}{a^2}$
$Bb^{n-4} - Cb^{n-5} \ldots \Big\} =$
$\cdot \frac{L}{b} + \frac{M}{b^2}$
$c^{n-4} - Cc^{n-5} \ldots \Big\} =$
$\frac{L}{c} + \frac{M}{c^2}$

ıations together, and for
ıluer, and it will be



$$\left.\begin{matrix} a^r - a^{r-1} \\ + b^r - b^{r-1} \\ + c^r - c^{r-1} \\ + \&c. - \&c. \end{matrix}\right\} \times A \left\{\begin{matrix} a^{r-2} \\ + b^{r-2} \\ + c^{r-2} \\ + \&c. \end{matrix}\right\} \times B \ldots .$$

$$\ldots \left\{\begin{matrix} -a \\ -b \\ -c \\ -\&c. \end{matrix}\right\} \times I + nK - \frac{L}{M} \times L + M \times \left\{\begin{matrix} +a^2 \\ +\beta^2 \\ +\gamma^2 \\ +\&c. \end{matrix}\right\} = 0.$$

But by the principle adduced from *pag.* 142, $a^2 + \beta^2 + \gamma^2 + \&c. = \frac{L^2}{M^2} - \frac{2K}{M}$: wherefore, by multiplication and tranſpoſition, it will follow that

$$2K - \frac{L}{M} \times L + M \times \left\{\begin{matrix} +a^2 \\ +\beta^2 \\ +\gamma^2 \\ +\&c. \end{matrix}\right\} = 0.$$

Which equation being ſubtracted from the preceding, there remains

$$\left.\begin{matrix} a^r - a^{r-1} \\ + b^r - b^{r-1} \\ + c^r - c^{r-1} \\ + \&c. - \&c. \end{matrix}\right\} \times A \left\{\begin{matrix} + a^{r-2} \\ + b^{r-2} \\ + c^{r-2} \\ + \&c. \end{matrix}\right\} \times B \ldots ,$$

$$\ldots \left\{\begin{matrix} -a \\ -b \\ -c \\ -\&c. \end{matrix}\right\} \times I + r \times K = 0.$$ Which was to be proved.

But to ſhew it *univerſally*, we may uſe the following LEMMA:

"That

" That if $A$ is the coefficient of one dimenſion, or the coefficient of the ſecond term, in an equation, $G$ any other coefficient, $H$ the coefficient next after it; the difference of the dimenſions of $G$ and $A$ being $r-2$: if likewiſe $A' \times G'$ repreſent the ſum of all thoſe terms of the product $A \times G$ in which the ſquare of any root, as $a^2$, or $b^2$, or $c^2$, &c. is found; then will $A' \times G' = AG - rH$."

This is a particular caſe of *Prop.* VI. concerning the *impoſſible roots* in *Phil. Tranſ.* N° 408; which, by continuing the Table of Equations in *pag.* 140, and obſerving how the coefficients are formed, may be thus demonſtrated.

Let the coefficient of a term of the equation, as $D (= abcd + abce + abcf$, &c. $+ bcde + bcdf$ &c.) be multiplied by $A (= a + b + c + d +$ &c.) and, in the product $A \times D$, ſetting aſide all the terms, $A' \times D'$, in which $a^2$, $b^2$, $c^2$, &c. are found, any one of the remaining terms will ariſe as often as there are factors in the terms of the following coefficient $E$. Thus the term *abcde* will ariſe *five* times: becauſe it is made up of any one of the five roots (or terms of $A$) $a, b, c, d, e$, multiplied into the other four that make a term of $D$: the like is true of every other term, as *abcdf*, *bcdef*, &c. each of which will ariſe *five* times in the product $A \times D$. And the ſum of theſe terms $abcde + abcdf +$ &c. making up the coefficient $E$, it follows that

$A \times$

That if $A$ is the coefficient of one dime
or the coefficient of the ſecond term;
ation, $G$ any other coefficient, $H$ the
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ns of $G$ and $A$ being $r-2$: if likew
repreſent the ſum of all thoſe terms
luct $A \times G$ in which the ſquare of a
$a^2$, or $b^2$, or $c^2$, &c. is found; the
$G' = AG - rH$."

s a particular caſe of *Prop.* VI. concer
*mpoſſible roots* in *Phil. Tranſ.* N° 42
y continuing the Table of Equation
go, and obſerving how the coefficient
d, may be thus demonſtrated.

coefficient of a term of the equatio
$bcd + abce + abcf$, &c. $+ bcde +$ &c.
multiplied by $A (= a + b + c + d +$ &c.
e product $A \times D$, ſetting aſide all th
$\times D'$, in which $a^2$, $b^2$, $c^2$, &c. a
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ife *five* times: becauſe it is multip
of the five roots (or terms of $A$
multiplied into the other four tha
m of $D$: the like is true of every
as $abcdf$, $bcdef$, &c. each of which
e times in the product $A \times D$. And
theſe terms $abcde + abcdf +$ &c.
the coefficient $E$, it follows that

$A \times D - A' \times D' = 5E$, or $A' \times D' = AD - 5E$.



And the ſame holds of any two coefficients $G$, $H$, whoſe dimenſions are $r-1$ and $r$ reſpectively.

To apply this to the preſent purpoſe, it is to be obſerved that, in each of the coefficients $A$, $B$, $C$, $D$, &c. except the laſt $M$, which is the product of all the roots $a$, $b$, $c$, $d$, &c. we may diſtinguiſh two ſeveral portions or members, in one of which any particular root, as $a$, is contained, but in the whole remaining portion of the ſame coefficient, that particular root ($a$) is wholly abſent. Now if, for brevity's ſake, we denote that portion of any coefficient wherein any root, as $a$, is contained, by annexing the ſymbol of the ſaid root with the ſign + in an *uncus* to the ſymbol, as $G$, of that coefficient (thus $G^{(+a}$;) and if we denote the remaining portion of the ſame coefficient, from which the ſame root $a$ is totally abſent by annexing the ſymbol of the ſaid root with the ſign — in an *uncus* to the ſymbol $G$ of the ſame coefficient (thus $G^{(-a}$) it will appear that (if $G$ be any coefficient and $H$ the following coefficient)

$$G = G^{(+a} + G^{(-a} \text{ and } H^{(+a} = aG^{(-a},$$
$$G = G^{(+b} + G^{(-b} \text{ and } H^{(+b} = bG^{(-b},$$
&c. &c.

Divide now the equation propoſed by $x^{n-r}$, and it will become

$$\left.\begin{array}{l} x^r - Ax^{r-1} + Bx^{r-2} - Cx^{r-3} \ldots\ldots \\ \ldots + Gx - H + \frac{I}{x} - \frac{K}{x^2} + \frac{L}{x^3} - \frac{M}{x^{n-r}} \end{array}\right\} = 0,$$

in which ſubſtituting $a$, $b$, $c$, &c. ſucceſſively for $x$, we obtain

$$\left.\begin{array}{l} a^r - Aa^{r-1} + Ba^{r-2} - Ca^{r-3} \ldots\ldots \\ \ldots + Ga - H + \frac{I}{a} - \frac{K}{a^2} + \frac{L}{a^3} - \frac{M}{a^{n-r}} \end{array}\right\} = 0,$$

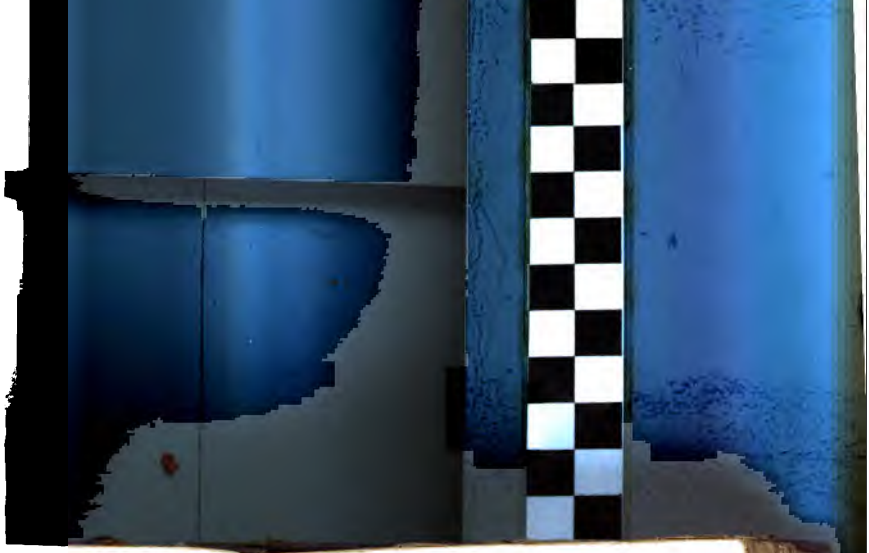
$$\left.\begin{array}{l} b^r - Ab^{r-1} + Bb^{r-2} - Cb^{r-3} \ldots\ldots \\ \ldots + Gb - H + \frac{I}{b} - \frac{K}{b^2} + \frac{L}{b^3} - \frac{M}{b^{n-r}} \end{array}\right\} = 0,$$

$$\left.\begin{array}{l} c^r - Ac^{r-1} + Bc^{r-2} - Cc^{r-3} \ldots\ldots \\ \ldots + Gc - H + \frac{I}{c} - \frac{K}{c^2} + \frac{L}{c^3} - \frac{M}{c^{n-r}} \end{array}\right\} = 0.$$

But, by the notation here uſed, and explained as above,

$$\begin{array}{ll} Ga = & aG^{(+a} + aG^{(-a} \\ -H = & \quad -aG^{(-a} - H^{(-a} \\ +\frac{I}{a} = & \quad +H^{(-a} + \frac{I}{a}^{(-a} \\ -\frac{K}{a^2} = & -\frac{I}{a}^{(-a} - \frac{K}{a^2}^{(-a} \\ +\frac{L}{a^3} = & \quad +\frac{K}{a^2}^{(-a} + \frac{L}{a^3}^{(-a} \\ -\frac{M}{a^{n-r}} = & \quad -\frac{L}{a^3}^{(-a} \text{ &c.} \end{array}$$

Whence





de now the equation proposed by r
vill become

$$\left.\begin{array}{l} {}^{1}x^{r-1} + Bx^{r-2} - Cx^{r-3} \ldots\ldots \\ {}^{1}x - H + \frac{I}{x} - \frac{K}{x^2} + \frac{L}{x^3} - \frac{M}{x^{r-r}} \end{array}\right\} =$$

fubſtituting $a$, $b$, $c$, &c. ſucceſſive
obtain

$$\left.\begin{array}{l} {}^{1}a^{r-1} + Ba^{r-2} - Ca^{r-3} \ldots\ldots \\ {}^{1}a - H + \frac{I}{a} - \frac{K}{a^2} + \frac{L}{a^3} - \frac{M}{a^{r-r}} \end{array}\right\} =$$

$$\left.\begin{array}{l} {}^{1}b^{r-1} + Bb^{r-2} - Cb^{r-3} \ldots\ldots \\ {}^{1}b - H + \frac{I}{b} - \frac{K}{b^2} + \frac{L}{b^3} - \frac{M}{b^{r-r}} \end{array}\right\} =$$

$$\left.\begin{array}{l} {}^{1}c^{r-1} + Bc^{r-2} - Cc^{r-3} \ldots\ldots \\ {}^{1}c - H + \frac{I}{c} - \frac{K}{c^2} + \frac{L}{c^3} - \frac{M}{c^{r-r}} \end{array}\right\} =$$

notation here uſed, and explain

$$\begin{array}{l} {}^{1}a + aG^{(-a} \\ \quad - aG^{(-a} - H^{(-a} \\ \qquad + H^{(-a} + \frac{I^{(-a}}{a} \\ -a \quad - \frac{K^{(-a}}{a^2} \\ \qquad - \frac{K^{(-a}}{a^2} + \frac{L^{(-a}}{a^3} \\ \qquad\quad - \frac{L^{(-a}}{a^3} \text{ \&c.} \end{array}$$

Whenc



Whence

$$Ga - H + \frac{I}{a} - \frac{K}{a^2} + \frac{L}{a^3} - \frac{M}{a^{n-r}} = aG^{(+a}$$

$$Gb - H + \frac{I}{b} - \frac{K}{b^2} + \frac{L}{b^3} - \frac{M}{b^{n-r}} = bG^{(+b}$$

$$Gc - H + \frac{I}{c} - \frac{K}{c^2} + \frac{L}{c^3} - \frac{M}{c^{n-r}} = cG^{(+c}$$

&c.

And the ſum of theſe $= aG^{(+a} + bG^{(+b} + cG^{(+c} + \&c. =$ (by this notation) $A \times G =$ (by the lemma)

$$\left.\begin{array}{l} +a \\ +b \\ +c \\ +\&c. \end{array}\right\} \times G - rH.$$

Compare this laſt concluſion with that which followed from dividing the propoſed equation by $x^{n-r}$, and ſubſtituting for $x$ the roots $a$, $b$, $c$, &c. and you will have

$$\left.\begin{array}{l} \left.\begin{array}{ll} a^r & -a^{r-1} \\ +b^r & -b^{r-1} \\ +c^r & -c^{r-1} \\ +\&c. & -\&c. \end{array}\right\} \times A \left\{\begin{array}{l} +a^{r-2} \\ +b^{r-2} \\ +c^{r-2} \\ +\&c. \end{array}\right\} \times C \ldots\ldots \\ \ldots\ldots\ldots\ldots \left\{\begin{array}{l} +a \\ +b \\ +c \\ +\&c. \end{array}\right\} \times G - rH \end{array}\right\} = 0,$$

which was to be demonſtrated.

From theſe two Theorems Sir *Iſaac Newton*'s Rule manifeſtly follows.

But, to illuſtrate the reaſoning here uſed by ſome examples: ſuppoſe $r = 3$, then we are to take $C$ for $H$, becauſe three terms only precede $C$ in the equation $x^n - Ax^{n-1} + Bx^{n-2} - Cx^{n-3} + \&c. = 0$; and we are to prove that

$$\left.\begin{matrix} a^1 \\ +b^1 \\ +c^1 \\ +d^1 \\ +\,\&c. \end{matrix}\right\} = \left.\begin{matrix} a^2 \\ +b^2 \\ +c^2 \\ +d^2 \\ +\,\&c. \end{matrix}\right\} \times \left.\begin{matrix} -a \\ -b \\ -c \\ -d \\ -\&c. \end{matrix}\right\} \times B + {}_3C.$$

That this may appear, obſerve that

$a^1 + b^1 + c^1 + d^1 + \&c. = \overline{a^2 + b^2 + c^2 + d^2} + \&c.$
$\times \overline{a + b + c + d} + \&c. - a^2 \times \overline{b + c + d} + \&c.$
$- b^2 \times \overline{a + c + d} + \&c. - c^2 \times \overline{a + b + d} + \&c.$
$- d^2 \times \overline{a + b + c} + \&c. - \&c. =$ (becauſe $A'B' =$
$a \times \overline{ab + ac + ad} + \&c. + b \times \overline{ab + bc + bd} + \&c.$
$+ c \times \overline{ac + bc + dc} + \&c. + d \times \overline{ad + bd + cd} + \&c.$
$+ \&c.) = \overline{a^2 + b^2 + c^2 + d^2} + \&c. \times A - AB'$
(by the Lemma) $= \overline{a^2 + b^2 + c^2 + d^2} + \&c.$
$\times A - AB + {}_3C.$

In like manner, $\overline{a^3 + b^3 + c^3 + d^3} + \&c. =$
$\overline{a^2 + b^2 + c^2 + d^2} + \&c. \times \overline{a + b + c + d} + \&c. -$
$\overline{a^2 + b^2 + c^2 + d^2} + \&c. \times \overline{ab + ac + ad + bc + bd + cd}$
$+ \&c. + a^2 \times \overline{bc + bd + cd} + \&c. + b^2 \times \overline{ac + ad + cd}$
$+ \&c.$

m these two Theorems Sir *Isaac Newton*
nanifeſtly follows.

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xamples: ſuppoſe $r = 3$, then we n
$C$ for $H$, becauſe three terms only pr
in the equation $x^n - Ax^{n-1} + \&c.$
$\&c. = 0$; and we are to prove the

$$\left.\begin{matrix} a^2 \\ +b^2 \\ +c^2 \\ +d^2 \\ +\ \&c. \end{matrix}\right\} = \left.\begin{matrix} -a \\ -b \\ -c \\ -d \\ -\&c. \end{matrix}\right\} \times A \left.\begin{matrix} \\ \\ \\ \\ \end{matrix}\right\} \times B$$

his may appear, obſerve the
$c^3 + d^3 + \&c. = \overline{a^2 + b^2 + c^2 + d^2 + \&c.} \times \overline{a + b + c + d + \&c.}$
$\overline{c+d} + \&c. - a^2 \times \overline{b + c + d + \&c.}$
$\overline{-c+d} + \&c. - c^2 \times \overline{a + b + d + \&c.}$
$\overline{-b+c} + \&c. - \&c. = (\text{because } \&c.$
$\overline{c+ad} + \&c. + b \times \overline{ab + ac + bd + \&c.}$
$\overline{bc+dc} + \&c. + d \times \overline{ad + bd + cd + \&c.}$
$\overline{a^2 + b^2 + c^2 + d^2} + \&c. \times A -$
emma) $= \overline{a^2 + b^2 + c^2 + d^2 + \&c.} \times$
$+ 3C.$

nanner, $\overline{a^2 + b^2 + c^2 + d^2 + \&c.} \times$
$\overline{+ d^2} + \&c. \times \overline{a + b + c + d + \&c.}$
$\overline{+ d^2} + \&c. \times \overline{ab + ac + ad + bc + bd +}$
$\overline{bc + bd + cd} + \&c. + b^2 \times \overline{ac + ad +}$
$+ \&c.$





$+ \&c. + c^2 \times \overline{ab + ad + bd} + \&c. + d^2 \times \overline{ab + ac + bc}$
$+ \&c. + \&c. = \overline{a^2 + b^2 + c^2 + d^2} + \&c. \times A$
$- \overline{a^2 + b^2 + c^2 + d^2} + \&c. \times B + AC =$
$\overline{a^2 + b^2 + c^2 + d^2} + \&c. \times A - \overline{a^2 + b^2 + c^2 + d^2}$
$+ \&c. \times B + \overline{a + b + c + d} + \&c. \times C - 4D.$

*End of the* SECOND PART.

A

# TREATISE

OF

# ALGEBRA.

## PART III.

Of the Application of *Algebra* and *Geometry* to each other.

### CHAP. I.

Of the Relation between the equations of Curve Lines and the figure of thoſe Curves, in general.

§ 1. IN the two firſt parts we conſidered Algebra as independent of Geometry; and demonſtrated its operations from its own principles. It remains that we now explain the uſe of Algebra in the reſolution of geometrical problems; or

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or reaſoning about geometrical figures; and the uſe of geometrical lines and figures in the reſolution of equations. The mutual intercourſe of theſe ſciences has produced many extenſive and beautiful Theories, the chief of which we ſhall endeavour to explain, beginning with the relation betwixt curve lines and their equations.

§ 2. We are now to conſider quantities as repreſented by *lines*; a *known* quantity by a *given* line, and an *unknown* by an *undetermined* line.

But as it is ſufficient that it be indetermined on one ſide, we may ſuppoſe one extremity to be known.




Thus the line AB, whoſe extremities A and B are both determined, may repreſent a given quantity: while AP, whoſe extremity P is undetermined, may repreſent an undetermined quantity. A leſſer undetermined quantity may be repreſented by AP, taking P nearer to A; and, if you ſuppoſe P to move towards A, then will AP, ſucceſſively, repreſent all quantities leſs than the firſt AP; and after P has coincided with A, if it proceed in the ſame direction to the place *p*, then will A*p* repreſent a negative quantity, if AP was ſuppoſed poſitive.

If AP repreſent $x$, and $Ap = AP$, then will $Ap$ repreſent $-x$; and for the ſame reaſon, if AB repreſent $(+a,)$ then will $Ab$ $(= AB)$ repreſent $(-a)$.

§ 3. After the ſame manner, if PM repreſent $+y$, and you take $Pm$, the continuation

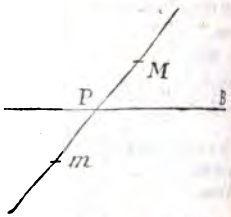



of PM on the other ſide, equal to PM, then will $Pm$ repreſent $-y$: for, by ſuppoſing M to move towards P, the line PM decreaſes; when M comes to P, then PM vaniſhes; and after M has paſſed P, towards $m$, it becomes negative.

§ 4. In Algebra, the root of an equation, when it is an impoſſible quantity, has its expreſſion; but in Geometry, it has none. In Algebra you obtain a general reſolution, and there is an expreſſion, in all caſes, of the thing required; only, within certain bounds, that expreſſion repreſents an *imaginary* quantity, or rather, "*is the ſymbol of an operation which, in that caſe, cannot be performed*;" and ſerves only

AP represent $x$, and $Ap = AP$, then will
represent $-x$; and for the same reason,
represent $(+a,)$ then will $Ab\,(=AB)$ =
$(-a)$.

After the same manner, if PM repr
and you take $Pm$, the continuation



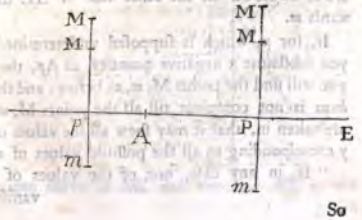

he other side, equal to PM, the
represent $-y$: for, by supposing M to
ds P, the line PM decreases; when
P, then PM vanishes; and after M
towards $m$, it becomes negative.
lgebra, the root of an equation,
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obtain a general resolution, and
ression, in all cases, of the thing
, within certain bounds, that ex-
ents an *imaginary* quantity, or
*symbol of an operation which*
*annot be performed*;" and serves
only



only to shew the *genesis* of the quantity, and the *limits* within which it is possible.

In the geometrical resolution of a question, the thing required is exhibited only in those cases when the question admits of a *real* solution; and, beyond those limits, no solution appears. So in finding the intersections of a given circle and a straight line, if you determine them by an equation, you will find two general expressions for the distances of the points of intersection from the perpendicular drawn from the center on the given line. But, geometrically, those intersections will be exhibited only when the distance of the straight line from the center is less than the radius of the given circle.

§ 5. "When in an equation there are two undetermined quantities, $x$ and $y$, then for each particular value of $x$, there may be as many values of $y$ as it has dimensions in that equation."




So

So that, if AP (a part of the indefinite line AE) represent $x$, and the perpendiculars PM represent the corresponding values of $y$, then there will be as many points (M, M) the extremities of these perpendiculars or *ordinates*, as there are dimensions of $y$ in the equation. And the values of PM will be the roots of the equation arising by substituting for $x$ its particular value AP in any case.

From which it appears, how, when an equation is given, you may determine as many of the points M as you please, and draw the line that shall pass through all these points; "which is called the *locus* of the equation."

§ 6. When any equation involving two unknown quantities ($x$ and $y$) is proposed, then substituting for $x$ any particular value AP, if the equation that arises has all its roots positive, the points M will lie on one side of AE; but if any of them are found negative, then these are to be set off on the other side of AE towards $m$.

If, for $x$, which is supposed undetermined, you substitute a negative quantity, as Ap, then you will find the points M, $m$, as before: and the *locus* is not compleat till all the points M, $m$, are taken in, that it may shew all the values of $y$ corresponding to all the possible values of $x$.

"If, in any case, one of the values of $y$ vanish,

vaniſh, then the point M coincides with P, and the *locus* meets with AE in that point."

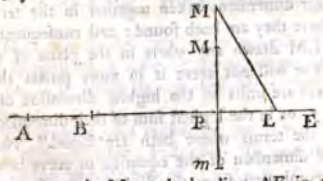
"If one of the values of $y$ becomes infinite, then it ſhews that the curve has an *infinite arc:* and, in that caſe, the line PM becomes an *aſymptote* to the curve, or touches it at an infinite diſtance," if AP is itſelf finite.

"If, when $x$ is ſuppoſed infinitely great, a value of $y$ vaniſh, then the curve approaches to AE produced as an aſymptote."

"If any values of $y$ become *impoſſible*, then ſo many points M vaniſh."

§ 7. From what has been ſaid it appears, that when an equation is propoſed involving two undetermined quantities ($x$ and $y$) "there may be as many interſections of the curve that is the *locus* of the equation, and of the line PM as there are dimenſions of $y$ in the equation; and as many interſections of the curve and the line AE as there are dimenſions of $x$ in the equation."

If you draw any other line LM meeting the

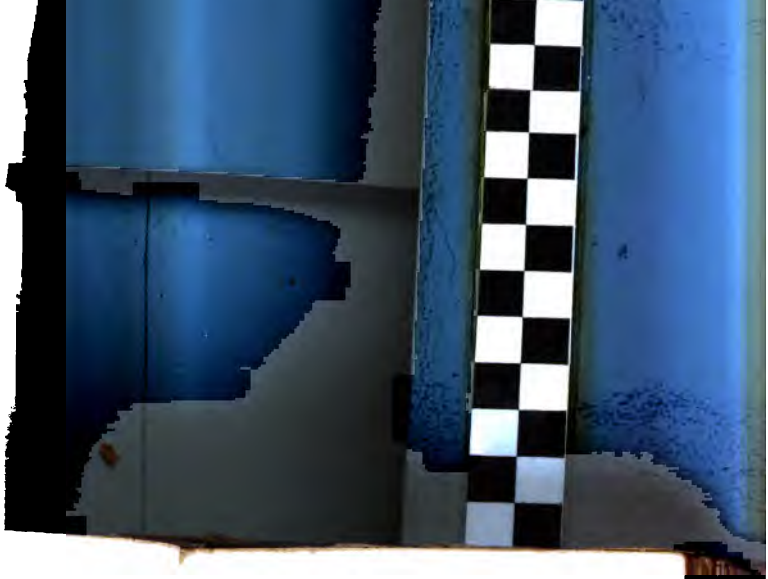



ſame curve in M, and the line AE in the given

given angle ALM. Suppoſe LM $= u$, and AL $= z$; "then the equation involving $u$ and $z$, ſhall not riſe to more dimenſions then $y$ and $x$ had in the propoſed equation, or, than the ſum of their dimenſions in any of its terms."

For, ſince the angles PLM, MPL, PML, are given, it follows that, the ſines of theſe angles being ſuppoſed to one another as $l$, $m$, $n$, PM : ML $(y : u) :: l : m$; and conſequently $y = \frac{lu}{m}$: and that PL : ML $:: n : m$; ſo that PL $= \frac{nu}{m}$, and $x =$ AP $(=$ AL $-$ PL$) = z - \frac{nu}{m}$. Subſtitute, for $y$ and $x$, in the propoſed equation theſe values $\frac{lu}{m}$ and $z - \frac{nu}{m}$, and it is obvious (ſince $u$ and $z$ are of one dimenſion only in the values of $y$ and $x$) that in the equation which will ariſe, $z$ and $u$ will not have more dimenſions than the higheſt dimenſion of $x$ and $y$ in the propoſed equation, or the higheſt ſum of their dimenſions taken together in the terms where they are both found: and conſequently, "LM drawn any where in the plane of the curve will not meet it in more points than there are units in the higheſt dimenſion of $x$ or $y$, or in the higheſt ſum of their dimenſions, in the terms where both are found." Now the dimenſion of the equation or curve being denominated from the higheſt dimenſion of $x$ or $y$ in it, or from the ſum of their dimenſions

where





ALM. Suppoſe LM = a
hen the equation involving x
ſe to more dimenſions than
propoſed equation, or, than
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the angles PLM, MPL, PE
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that PL : ML :: x : u; i
x = AP (= AL − PL) = $\frac{u}{m}$
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rom the ſum of their dimenſions
where



where they are moſt; we conclude, that "the number of points in which the curve can meet with any ſtraight line, is equal to the number that expreſſes the dimenſion of the curve."

It appears alſo from this article, how, when an equation of a curve is given expreſſing the relation of the ordinate PM and abſciſſe AP, you may transform it, ſo as to expreſs the relation between any other ordinate ML and the abſciſſe AL, by ſubſtituting for $y$ its value $\frac{lu}{m}$, and for $x$ its value $z - \frac{nu}{m}$.

Or, if you would have the abſciſſe begin at any other point B, ſuppoſing $AB = e$, ſubſtitute for $x$ not $z - \frac{nu}{m}$, but $z - \frac{nu}{m} + e$.

§ 8. Thoſe curve lines that can be deſcribed by the reſolution of equations, the relation of whoſe ordinates PM and abſciſſes AP can be expreſſed by an equation involving nothing but determined quantities beſides theſe ordinates and abſciſſes, are called "*geometrical* or *algebraic* curves."

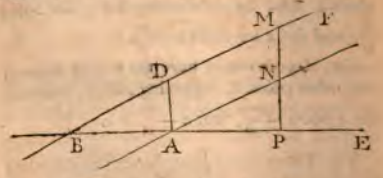
They are divided into *orders* according to the dimenſions of their equations, or number of points in which they can interſect a ſtraight line.

The *ſtraight lines* themſelves conſtitute the *firſt* order of lines; and when the equation expreſſing the relation of $x$ and $y$ is of one dimenſion

dimenſion only, the points M muſt be all found in a ſtraight line conſtituting a given angle with AE.

Suppoſe, for example, that the equation given is $ay - bx - cd = 0$, and that the *locus* is required.

Since $y = \frac{bx+cd}{a}$, it follows, that, APM being a right angle, if you draw AN making the



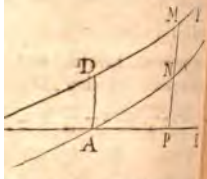

angle NAP ſuch that its coſine be to its ſine as $a$ to $b$; and drawing AD parallel to the ordinates PM, and equal to $\frac{cd}{a}$, through D you draw DF parallel to AN, DF will be the locus required. Where you are to take AD on the ſame ſide of the line AE, with PN, if $bx$ and $cd$ have the ſame ſign, but on the contrary ſide of AE if they have contrary ſigns.

§ 9. Thoſe curves whoſe equations are of *two* dimenſions conſtitute the *ſecond order* of lines, and the *firſt kind* of *curves*. Their interſections

only, the points M must be all in
ıt line conſtituting a given angle

, for example, that the equation
$- cd = 0$, and that the lines

$= \frac{bx + cd}{a}$, it follows, that, APM
angle, if you draw AN making




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Where you are to take AD on
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ſe curves whoſe equations are
ons conſtitute the *ſecond order*
he *firſt kind of curves*. Their
terſection



terſections with a ſtraight line can never exceed two, by § 7.

The curves whoſe equations are of *three* dimenſions from the *third order* of lines, or *ſecond kind* of *curves*: and their interſections with a ſtraight line can never exceed Three. And, after the ſame manner, the curves are determined that belong to the *higher* orders, to infinity.

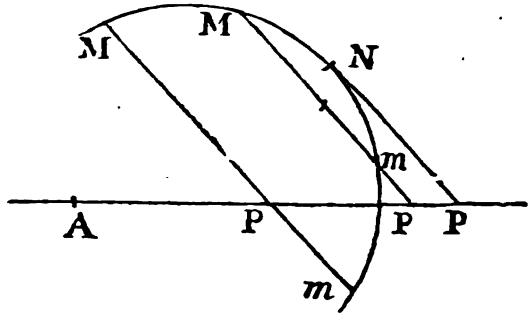
Some curves, if they were completely deſcribed, could cut a ſtraight line in an infinite number of points; but theſe belong to none of the orders we have mentioned; they are not geometrical or algebraic curves, for the relation betwixt their ordinates and abſciſſes cannot be expreſſed by a finite equation involving only ordinates and abſciſſes with determined quantities.

§ 10. As "the roots of an equation become impoſſible always in pairs, ſo the interſections of the curve and its ordinate PM muſt vaniſh in pairs," if any of them vaniſh.

Let PM cut the curve in the points M and *m*, and by moving parallel to itſelf come to touch it in the point N; then the two points of interſection, M and *m*, go into one point of contact N. If PM ſtill move on parallel to itſelf, the points of interſection will, beyond

N

N, become imaginary; as the two roots of

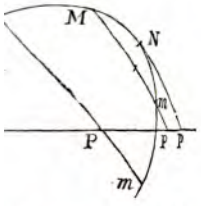



an equation firſt become equal and then imaginary.

§ 11. The curves of the 3d, 5th, 7th orders, and all whoſe dimenſions are odd numbers, muſt have, at leaſt, two infinite arcs; ſince equations whoſe dimenſions are odd numbers have always one real root *at leaſt*; and conſequently, for every value of $x$, the equation by which $y$ is determined muſt, at leaſt, have one real root: ſo that as $x$ (or AP may be increaſed *in infinitum* on both ſides, it follows that M muſt go off *in infinitum* on both ſides, without limit.

Whereas, in the curves whoſe dimenſions are even numbers, as the roots of their equations may become all impoſſible, it follows that the figure of the curve may be like a *circle* or *oval* that

ıe imaginary; as the two roots




firſt become equal and then

ıe curves of the 3d, 5th, 7th
whoſe dimenſions are odd numbers
at leaſt, two infinite arcs; and
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that is limited within certain bounds, beyond which it cannot extend.

§ 12. When two roots of the equation by which $y$ is determined become equal, either "the ordinate PM touches the curve," two points of interſection, in that caſe, going into a point of contact; or, "the point M is a *punctum duplex* in the curve;" two of its arcs interſecting each other there: or, "ſome oval that belongs to that kind of curve becoming infinitely little in M, it vaniſhes into what is called a *punctum conjugatum*."

If, in the equation, $y$ be ſuppoſed $= 0$, then "the roots of the equation by which $x$ is determined, will give the diſtances of the points where the curve meets AE from A." And, if two of thoſe roots be found equal, then either "the curve *touches* the line AE;" or, "AE paſſes through a *punctum duplex* in the curve." When $y$ is ſuppoſed $= 0$, if one of the values of $x$ vaniſh, the curve, in that caſe, paſſes through A." If two vaniſh, then either "AE touches the curve in A;" or, "A is a *punctum duplex*."

"As a *punctum duplex* is determined from the equality of two roots, ſo is a *punctum triplex* determined from the equality of *three* roots.

§ 13. A few examples will make theſe obſervations very plain. Suppoſe it is required to deſcribe the line that is the *locus* of this equa-

tion, $y^2 = ax + ab$, or $y^2 - ax - ab = 0$. Since $y = \pm\sqrt{ax+ab}$, and ſince $a$ and $b$, are given in variable quantities, if you aſſume AP ($=x$) of a known value, it will be eaſy to find $\sqrt{ax+ab}$; and ſetting off PM on one ſide equal to $\sqrt{ax+ab}$, and P$m$ on the other equal to PM, the points M and $m$ will belong to the locus required. And for every poſitive value of AP you will thus obtain a point of the locus on each ſide. The greater AP ($=x$) is taken, the greater does the $\sqrt{ax+ab}$ become, and conſequently PM and P$m$ become the greater.

If AP be ſuppoſed infinitely great, PM and P$m$ will alſo become infinitely great; and conſequently the locus has two infinite arcs that go off to an infinite diſtance from AE and from AD. If you ſuppoſe $x$ to vaniſh, $y = \pm\sqrt{ab}$; ſo that $y$ does not vaniſh in that caſe but paſſes through D and $d$, taking AD and A$d = \sqrt{ab}$ a mean proportional betwixt $a$ and $b$.

If you now ſuppoſe that the point P moves to the other ſide of A, then you muſt, in the equation, ſuppoſe $x$ to become negative, and $y = \pm\sqrt{ab-ax}$; ſo that $y$ will have two values as before, while $x$ is leſs than $b$. But if AB$= b$, and you ſuppoſe the point P to come to B, then $ab = ax$, and $y = \pm\sqrt{ab-ax} = 0$. That is, PM and P$m$ vaniſh; and the curve there meets the line AE. If you ſuppoſe P to move from

A

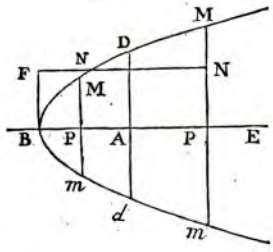
$y^2 = ax + ab$, or $y^2 - ax - ab = 0$. Sol
$\sqrt{ax+ab}$, and since $a$ and $b$, are given
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A



A beyond B, than $x$ becomes greater than $b$, and $ax$ greater than $ab$, ſo that $ab-ax$ being




negative, $\sqrt{ab-ax}$ becomes imaginary, and the two values of $y$ become imaginary; that is, beyond B there are no ordinates that meet the curve, and conſequently, on that ſide, the curve is limited in B.

All this agrees very well with what is known by other methods, that the curve whoſe equation is $y^2 = ax + ab$, is a parabola whoſe vertex is B, axis BE, and parameter equal to $a$. For ſince BP $= b \pm x$, and PM $= y$, if BE be equal to $a$; then the rectangle BN $(= ab \pm ax)$ will be equal to PM$q$ $(= y^2)$ which is the known property of the *parabola*. And it is obvious, that the figure of the parabola is ſuch as we

have determined this locus to be from the conſideration of its equation.

§ 14. Let it be required to deſcribe the line that is the *locus* of this equation, $xy + ay + cy = bc + bx$, or $y = \frac{bc+bx}{a+c+x}$.

Here, it is plain, the ordinate PM can meet the curve in one point only, there being but one value of $y$ correſponding to each value of $x$. When $x=0$, then $y = \frac{bc}{a+c}$, ſo that the curve does not paſs through A. If $x$ be ſuppoſed to increaſe, then $y$ will increaſe, but will never become equal to $b$, ſince $y = b \times \frac{c+x}{a+c+x}$, and $a + c + x$ is always greater than $c + x$. If $x$ be ſuppoſed infinite, then the terms $a$ and $c$ vaniſh compared with $x$, and conſequently $y = b \times \frac{x}{x} = b$; from which it appears, that taking AD $= b$, and drawing GD parallel to AE, it will be an *aſymptote*, and touch the curve at an infinite diſtance.

If $x$ be now ſuppoſed negative, and AP be taken on the other ſide of A, then ſhall $y = b \times \frac{c-x}{a+c-x}$; and if $x$ be taken, on that ſide, $= c$, then ſhall $y = b \times \frac{c-c}{a} = 0$; ſo that the curve muſt paſs through B, if AB $= c$.

If $x$ be ſuppoſed greater than $c$, then will $c - x$

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§ 14. Let it be required to describe the
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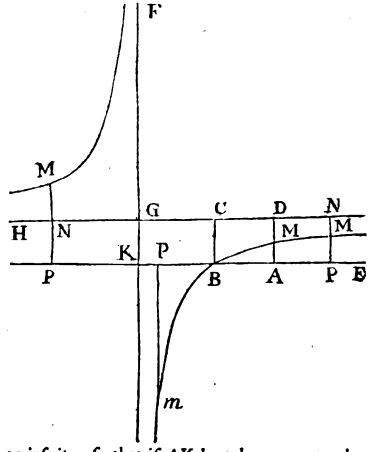
e now supposed negative, and M
on the other side of A, then bei
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then shall $y=b\times\frac{c-c}{a}=0$; so that
must pass through B, if $AB=c$.
ppposed greater than $c$, then will $c-x$
gative, and the ordinate will become





negative and lie on the other side of AE, till $x$ becomes equal to $a+c$, and then $y=b\times\frac{-a}{0}$,




or *infinite*; so that if AK be taken $=a+c$, the ordinate KL will be an *asymptote* to the curve.

If $x$ be taken greater than $a+c$, or AP greater than AK, then both $c-x$ and $a+c-x$ become negative; and consequently $y\left(=b\times\frac{x-c}{x-a-c}\right)$ becomes positive; and since $x-c$ is always

greater than $x-a-c$, it follows that $y$ will be always greater than $b$ or KG, and conſequently the reſt of the curve lies in the angle FGH. And, as $x$ increaſes, ſince the ratio of $x-c$ to $x-a-c$ approaches ſtill nearer to a ratio of equality, it follows that PM approaches to an equality with PN, and the curve to its aſymptote GH on that ſide alſo.

This curve is the common *hyperbola*; for ſince $b \times \overline{c+x} = y \times \overline{a+c+x}$, by adding $ab$ to both ſides $b \times a+c+x = y \times a+c+x+ab$; and $b-y \times a+c+x = ab$; that is, NM × GN = GC × BC, which is the property of the common hyperbola. And it is eaſy to ſee how the figure of the *locus* we have been conſidering agrees with the figure of the hyperbola.

§ 15. Let it be required to deſcribe the *locus* of the equation $y^3 - xy^2 = x^3 + bx^2$. Where, ſince $y^2 = \frac{x^3+bx^2}{c-x}$ and $y = \pm\sqrt{\frac{x^3+bx^2}{c-x}}$, it follows that PM and P$m$ muſt be taken equal, on both ſides, to $\sqrt{\frac{x^3+bx^2}{c-x}}$. But that when $x$ is taken equal to $c$, if AB $= c$, and BK be perpendicular to AB, then BK muſt be an *aſymptote* to the curve. If $x$ be ſuppoſed greater than $c$, or AP greater than AB, then $c-x$ being negative, the fraction $\frac{x^3+bx^2}{c-x}$ will become negative, and its ſquare root impoſſible. So that no part of

of the *locus* can be found beyond B. If $x$ be ſuppoſed negative, or P taken on the other ſide of A, then $y = \pm\sqrt{\frac{-x^3+bx^2}{c+x}}$, the ſign of $x^3$ and $x$ being changed, but not the ſign of $bx^2$; becauſe the ſquare of a negative is the ſame as the ſquare of a poſitive, but its cube is negative: while $x$ is leſs than $b$, the values of $y$ will be real and equal; but if $x = b$, then the values of $y$ vaniſh, becauſe, in that caſe,

$y = \pm\sqrt{\frac{-x^3+bx^2}{c-x}} = \sqrt{\frac{-b^3+b^3}{c-x}} = 0$; and conſequently, if AD be taken $= b$, the curve will paſs through D, and there touch the ordinate.

If $x$ be taken greater than $b$, then $\pm\sqrt{\frac{-x^3+bx^2}{c+x}}$ will become *imaginary*, ſo that no part of the curve is found beyond D.

If you ſuppoſe $y = 0$, then will $x^3 + bx^2 = 0$



be an equation whose roots are $-b$, 0, 0, from which it appears that the curve passes twice through the point A, and has, in A, a *punctum duplex*. This *locus* is a line of the third order, BK is its asymptote, and it has a *nodus* betwixt A and D.

If you suppose $b$ to vanish in the equation, so that $cy^2 - xy^2 = x^3$, then will A and D coin-

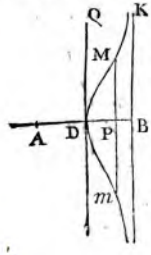



cide, and the *nodus* vanish, and the curve will have in the point A a *cuspis*, the two arcs AM and

and Am touching one another in that point. And this is the ſame curve which by the ancients was called the *ciſſoid* of *Diocles*, the line AB being the diameter of the generating circle, and BK the aſymptote.

For, if BR be equal to AP, and the ordinate RN be raiſed meeting the circle in N, and AN be drawn, it will cut the perpendicular PM in M a point of the ciſſoid. So that if M be a point in the ciſſoid, AP : PM :: AR : RN :: $\surd$AR : $\surd$BR :: $\surd$BP : $\surd$AP, and conſequently, BP $\times$ PM$^2$ = AP cub. that is, $\overline{c-x} \times y^2 = x^3$ : which is the equation the *locus* of which was required.

If, inſtead of ſuppoſing $b$ poſitive, or equal to nothing, we now ſuppoſe it negative, the equation will be $cy^2 - xy^2 = x^3 - bx^2$, the curve will paſs through D, as before, and taking AB $= c$, BK will be its aſymptote: it will have a *punctum conjugatum* in A, becauſe when $y$ vaniſhes, two values of $x$ vaniſh, and the third becomes equal to $b$ or AD. The whole curve, beſides this *point* A, lies between DQ and BK. Theſe are demonſtrated after the ſame manner as in the firſt caſe.

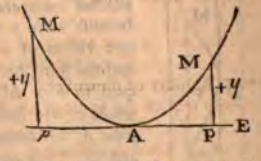



§ 16.

§ 16. If an equation is propoſed, as $y = ax^n + bx^{n-1} + cx^{n-2}$, &c. and $n$ is an even number, then will the *locus* of the equation have two infinite arcs lying on the ſame ſide of AE. For, if $x$ become infinite, whether poſitive or negative, $x^n$ will be poſitive, and $ax^n$ have the ſame ſign in either caſe; and as $ax^n$ becomes infinitely greater than the other terms $bx^{n-1}$, $cx^{n-2}$, &c. it follows that the infinite values of $y$ will have the ſame ſign in theſe caſes; and conſequently, the two infinite arcs of the curve will lie on the ſame ſide of AE.

But if $n$ be an odd number, then when $x$ is negative, $x^n$ will be negative, and $ax^n$ will have the contrary ſign to what it has when $x$ is poſitive; and therefore the two infinite arcs, in this caſe, will lie on different ſides of AE, and tend towards parts directly oppoſite.

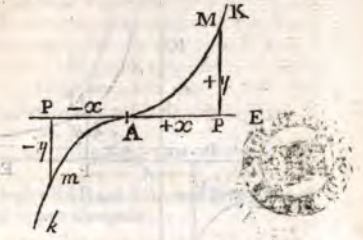
Thus the locus of the equation $ay = x^2$ is the parabola. A is the vertex, AE is the tan-




gent at the vertex; and the two infinite arcs lie manifeſtly on the ſame ſide of AE.

But

But the *locus* of the equation $a^3y = x^3$, where the index of $x$ is an odd number, has its two

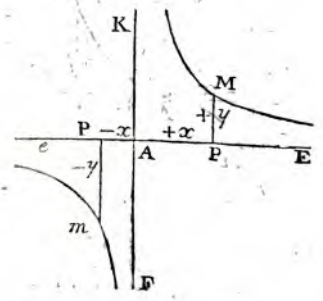



arcs on different ſides of AE, tending towards oppoſite parts, as AMK, and A*mk*. This curve is called the *cubical parabola*, and is a line of the third order.

The *locus* of the equation $a^3y = x^4$ is of a figure like the common parabola; and "all thoſe loci, in whoſe equations $y$ is of one dimenſion, $x$ of an *even* number of dimenſions: But thoſe *loci* are like the cubical parabola, in whoſe equations $y$ is of one dimenſion only, and $x$ of an *odd* number of dimenſions." And this Rule is even true of the locus of the equation $y = x$, which is a ſtraight line cutting AE in an angle of 45°; which manifeſtly goes off as the cubical parabola does to infinity, towards oppoſite parts, and on different ſides of AE.

§ 17.

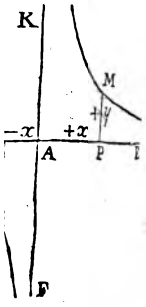
§ 17. If the *locus* of the equation $yx^n = a^{n+1}$ is required;




If $n$ is an *odd* number, then when $x$ is positive, $y = \frac{a^{n+1}}{x^n}$; but when $x$ is negative, then $y = -\frac{a^{n+1}}{x^n}$; so that this curve must all lie in the vertically *opposite* angles KAE, FAE, (as the common *hyperbola*:) FK, E*e*, being asymptotes.

But if $n$ is an *even* number, then $y$ is always positive, whether $x$ be positive or negative, because $x^n$, in this case, is always positive; and there-

locus of the equation $y^2 = x$




number, then when $x$ is po

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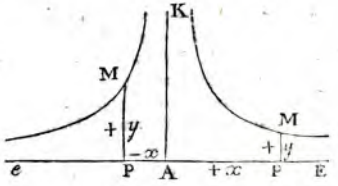
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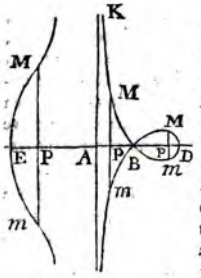


therefore the curve muſt all lie in the two *ad-*




*jacent* angles KAE and KA*e*, and have AK and AE for its two aſymptotes.

§ 18. Let the equation given be $\overline{a^2 - x^2} \times \overline{x - b}^2 = x^2 y^2$; ſo that $y = \pm \sqrt{a^2 - x^2} \times \frac{x - b}{x}$.




If $x = 0$, then $y$ becomes infinite, and therefore the ordinate at A is an *aſymptote* to the curve. If AB $= b$, and P be taken betwixt A and B, then ſhall PM and P$m$ be equal, and lie on different ſides of the abſciſſe AP. If $x = b$, then the two values of $y$ vaniſh, becauſe

becauſe $x-b=0$; and conſequently, the curve paſſes through B, and has there a *punctum duplex*. If AP be taken greater than AB, then ſhall there be two values of $y$, as before, having contrary ſigns, that value which was poſitive before being now become negative, and the negative value being become poſitive. But if AD be taken $= a$, and P comes to D, then the two values of $y$ vaniſh, becauſe $\sqrt{a^2-x^2}=0$. And if AP is taken greater than AD, then $a^2-x^2$ becomes negative, and the value of $y$ *impoſſible*: and therefore, the curve does not go beyond D.

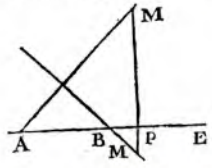
If $x$ now be ſuppoſed negative, we ſhall find $y=\pm\sqrt{a^2-x^2}\times\overline{b+x}\div x$. If $x$ vaniſh, both theſe values of $y$ become infinite, and conſequently, the curve has two infinite arcs, on each ſide of the *aſymptote* AK. If $x$ increaſe, it is plain $y$ diminiſhes, and if $x$ becomes $= a$, $y$ vaniſhes, and conſequently the curve paſſes through E, if AE be taken $=$ AD, on the oppoſite ſide. If $x$ be ſuppoſed greater than $a$, then $y$ becomes *impoſſible*; and no part of the curve can be found beyond E. This curve is the *conchoid* of the ancients.

If $a=b$, it will have a *cuſpis* in B, the nodus betwixt B and D vaniſhing. And if $a$ is leſs than $b$, the point B will become a *punctum conjugatum*.

From

From what has been ſaid an error may be corrected of an Author in the *Memoires de l'Acad. Royale des Sciences*, who gives this curve no infinite arcs, but only a *double nodus*. Some other errors of the ſame kind may be corrected in that Treatiſe, from what we have ſaid.

§ 19. If the propoſed equation can be reſolved into two equations of lower dimenſions, without affecting either $y$ or $x$ with any radical ſign, then the *locus* ſhall conſiſt of the two *loci* of thoſe inferior equations. Thus the locus of the equation $y^2 - 2xy + by + x^2 - bx = 0$ is found to be two ſtraight lines cutting the ab-




ſciſſe AE in angles of 45°, in the points A and B, whoſe diſtance AB $= b$, becauſe that equation is reſolved into theſe two $y - x = 0$, and $y - x + b = 0$.

After the ſame manner, ſome *cubic* equations can be reſolved into three ſimple equations, and then the *locus* is *three* ſtraight lines; or may be reſolved into a *quadratic* and *ſimple* equation,

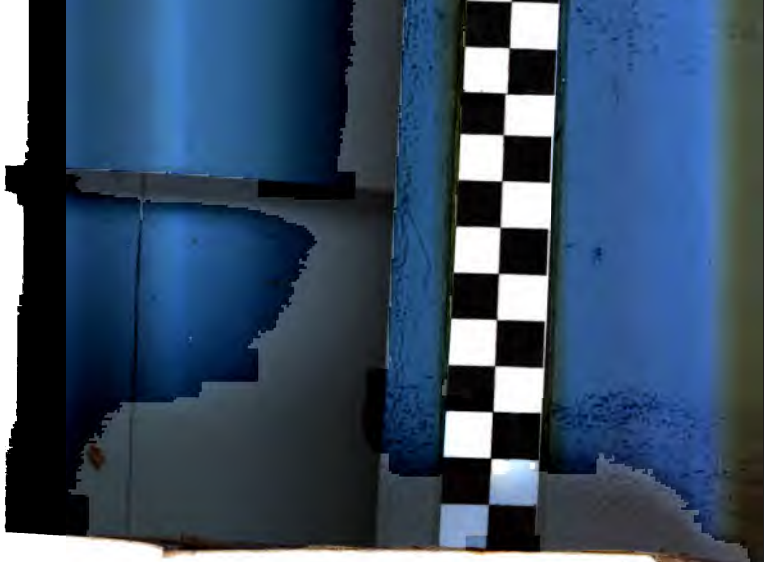
equation, and then the *locus* is a *conic ſection* and a *ſtraight line*.

*In general*, " the curves of the ſuperior orders include all the curves of the inferior orders; and whatever is demonſtrated generally of any one order, is alſo true of the inferior orders." So, for example, any general property of the conic ſections hold true of two ſtraight lines as well as of a conic ſection. Particularly that " the rectangles of the ſegments of parallels bounded by them, will be always to one another in a given ratio." The general properties of the lines of the third *order* are true of three ſtraight lines, or of any one ſtraight line and a conic ſection. And, as the general properties of the higher orders of lines deſcend alſo to thoſe of the inferior orders, ſo there is ſcarce any property of the inferior orders, but has an analogy to ſome property of the higher orders; of which it is but a particular caſe or inſtance. And hence, the properties of the inferior orders lead to the diſcovery of thoſe of the ſuperior orders *.

§ 20. We have ſhewed how to judge of the figure of a *locus* from the conſideration of its equation. And when a *locus* is to be deſcribed exactly, for every value of $x$ you muſt, by the reſolution of equations, according to the Rules

* See the APPENDIX.

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in *Part* II. find the correſponding values of *y*, and determine from theſe values the points of the *locus*.

But there are geometrical *conſtructions* by which the roots of equations can be determined more commodiouſly for this purpoſe. And, as by theſe conſtructions we deſcribe the *loci* of the equations, ſo reciprocally when *loci* are deſcribed, they are uſeful in determining the roots of equations; both which ſhall be explained in the following *Chapter*. Then we ſhall give an account of the moſt general and ſimple methods of deſcribing theſe *loci* by the mechanical motion of angles and lines, whoſe interſections trace the curve; or of conſtructing them by finding geometrically any number of their points.

## CHAP. II.

### Of the Conſtruction of Quadratic Equations; and of the Properties of the Lines of the ſecond order.

§ 21. THE general equation expreſſing the nature of the lines of the ſecond order, having all its terms and coefficients, will be of this form;

$$\left.\begin{matrix} y^2 + axy + cx^2 \\ + by + dx \\ + e \end{matrix}\right\} = 0.$$

Where $a, b, c, d, e$, repreſent any given quantities with their proper ſigns prefixed to them.

If a quadratic equation is given, as $y^2 + py + q = 0$, and, by comparing it with the preceding, if you take the quantities $a, b, c, d, e$, and $x$ ſuch that $ax + b = p$, and $cx^2 + dx + e = q$, then will the values of $y$ in the firſt equation be equal to the values of it in the ſecond; and if the *locus* be deſcribed belonging to the firſt equation, the two values of the ordinate when $ax + b = p$ and $cx^2 + dx + e = q$, will be the two roots of the equation $y^2 + py + q = 0$.

And as *four* of the given quantities $a, b, c, d, e$, may be taken at pleaſure, and the *fifth*, with

## HAP. II.

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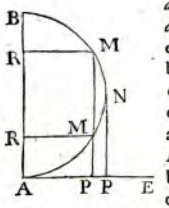
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with the abſciſſe $x$, determined, ſo that $ax + b$ may be ſtill equal to $p$, and $cx^2 + dx + e = q$; hence there are innumerable ways of conſtructing the ſame equation. But thoſe *loci* are to be preferred which are deſcribed moſt eaſily; and therefore, the *circle*, of all conic ſections, is to be preferred for the reſolution of quadratic equations.

§ 22. Let AB be perpendicular to AE, and upon AB deſcribe the ſemicircle BMMA. If AP be ſuppoſed equal to $x$, AB $= a$, and PM $= y$, then making MR, MR, perpendiculars to the diameter AB, ſince AR × RB = RM$q$, and AR $= y$, RB $= a - y$, RM $= x$, it follows that $\overline{a - y} \times y = x^2$, and $y^2 - ay + x^2 = 0$. And, if an equation $y^2 - py + q = 0$, be propoſed to be reſolved, its roots will be the ordinate to the circle, PM and PM, to its tangent AE, if $a = p$, and $x^2 = q$: becauſe then the equation of the circle $y^2 - ay + x^2 = 0$, will be changed into the propoſed equation $y^2 - py + q = 0$.




We have therefore this conſtruction for finding the roots of the quadratic equation $y^2 - py + q = 0$; take AB $= p$, and on AB deſcribe a

ſemicircle; then raiſe AE perpendicular to AB, and on it take AP $= \sqrt{q}$, that is, a mean proportional between 1 and $q$ (*by* 13 *El.* 6.) then draw PM parallel to AB, meeting the ſemicircle in M, M, and the lines PM, PM ſhall be the roots of the propoſed equation.

It appears from the conſtruction that if $q = \frac{p^2}{4}$, or $\sqrt{q} = \frac{1}{2}p$, then AP $= \frac{1}{2}$AB, and the ordinate PN touches the curve in N, the two roots PM, PM, in that caſe, becoming equal to one another and PN.

If AP be taken greater than $\frac{1}{2}$AB, that is, when $\sqrt{q}$ is greater than $\frac{1}{2}p$, or $q$ greater than $\frac{1}{4}p^2$, the ordinates do not meet the circle, and the roots of the equation become *imaginary:* as we demonſtrated, in another manner, in *Part* II.

§ 23. The roots of the ſame equation may be otherwiſe thus determined.

Take AB $= \sqrt{q}$, and raiſe BD perpendicular to AB; from A as a center with a radius equal to $\frac{1}{2}p$, deſcribe a circle meeting BD in C, then the two roots of the equation $y^2 - py + q = 0$, ſhall be AC + CB, and AC − CB.

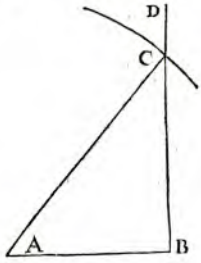
For theſe roots are $\frac{1}{2}p + \sqrt{\frac{1}{4}p^2 - q}$, and $\frac{1}{2}p - \sqrt{\frac{1}{4}p^2 - q}$; and AC $= \frac{1}{2}p$, CB $= \sqrt{AC^2 - CB^2} = \sqrt{\frac{1}{4}p^2 - q}$, and conſequently theſe roots are AC ± CB.

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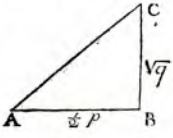
The roots of the equation $y^2 + py + q = 0$ are




$= AC \pm CB$; as is demonſtrated in the ſame manner.

§ 24. The roots of the equation $y^2 - py - q = 0$ are determined by this conſtruction.

Take $AB = \frac{1}{2}p$, $BC = \sqrt{q}$, draw AC; and the two roots ſhall be $AB \pm AC$. If the ſe-




cond term is poſitive, then the roots ſhall be $-AB \pm AC$.

And all quadratic equations being reducible to theſe four forms,

$$y^2 - py + q = 0,$$
$$y^2 + py - q = 0,$$
$$y^2 - py - q = 0,$$
$$y^2 + py + q = 0,$$

it follows, that they may be all conſtructed by this and the laſt two articles.

§ 25. By theſe geometrical conſtructions, the locus of any equation of two dimenſions may be deſcribed; ſince, by their means, the values of $y$ that correſpond to any given value of $x$ may be determined. But if we demonſtrate that theſe *loci* are always *conic ſections*, then they may more eaſily be deſcribed by the methods that are already known for deſcribing theſe curves.

In order to prove this, we ſhall enquire what equations belong to the different *conic ſections*; and, as it will appear that there is no equation of two dimenſions but muſt belong to one or other of them, it will follow that they are the of all equations of two dimenſions.

§ 26. Let CML be a *parabola*; AE a line drawn in the ſame plane; and let it be required to find the equation expreſſing the relation betwixt the ordinate PM forming a given angle with AE, and the abſciſſe

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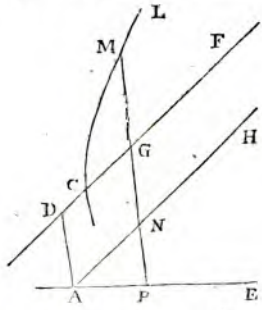
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Let CF be the diameter of the parabola whoſe ordinates are parallel to PM. Draw AH parallel to CF meeting PM in N; and AD parallel to PM meeting CF in D. Becauſe the angles HAE, APN, ANP, are given the lines AP, PN, AN, will be in a given ratio to each other: ſuppoſe them to be always as $a$, $b$, $c$; let AD $= d$, DC $= e$; and ſeeing AP $(= x)$ : PN :: $a$ : $b$, PN $= \frac{b}{a}x$; likewiſe AP : AN :: $a$ : $c$, or AN $= \frac{c}{a}x$. And GM $=$ PM $-$ PN $-$ NG $= y - \frac{b}{a}x - d$. But CG $=$ DG $-$ DC

$C = \frac{c}{a}x - e$. If now the

diameter CL be called $t$, the

of the parabola, $p \times CG = GM$

$p \times \frac{c}{a}x - e = y - \frac{b}{a}x - d$

equation follows,

$$\left. - 2dy + \frac{2bd}{a} \right\} + p^2 \Bigg\} =$$
$$\left. - \frac{pc}{a} \right\} + p \Bigg\}$$

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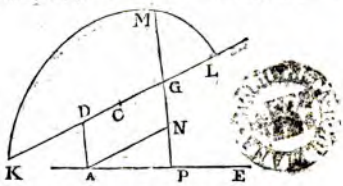
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wants both the terms, $xy$ and $x^2$, it may be always accommodated to a *parabola*.

§ 28. The general equation for the *ellipſe* is deduced from the property of the ordinates of any diameter, in the ſame manner; the conſtruction of the figure being the ſame as in § 26. Only, in place of the *parabola*,

Let KML be an *ellipſe* whoſe diameter is KL, having its ordinates parallel to PM, and




let C be the center of the *ellipſe*. Suppoſe $CL = t$, and the *parameter* of that diameter $= p$, then $GMq : CLq - CGq :: p : 2t$. But, as in § 26, $GM = y - \frac{b}{a}x - d$, and $CG = \frac{c}{a}x - e$; therefore, $\overline{y - \frac{b}{a}x - d}^2 \times \frac{2t}{p} = t^2 - \frac{c^2}{a^2}x^2 + \frac{2ce}{a}x - e^2$: whence this equation;

$$\left. y^2 - \frac{2b}{a}xy + \frac{b^2}{a^2} \right\} - 2dy + \frac{2bd}{a} \Bigg\} + d^2 \Bigg\}$$
$$\left. + \frac{pc^2}{2ta^2} \right\} x^2 \quad \left. - \frac{pce}{at} \right\} x - \frac{pt}{2} \Bigg\} = 0.$$
$$\left. + \frac{pe^2}{2t} \right\}$$

And

$DC = AN - DC = \frac{c}{a}x - e$. If now the *parameter* of the diameter CF be called $p$, then, from the nature of the parabola, $p \times CG = GM^2$: and consequently, $p \times \frac{c}{a}x - e = \left|y - \frac{b}{a}x - d\right|^2$, from which this equation follows,

$$y^2 - \frac{2b}{a}xy + \frac{b^2}{a^2}x^2 - 2dy + \left.\begin{array}{l}\frac{2bd}{a} \\ -\frac{pc}{a}\end{array}\right\} x + \left.\begin{array}{l}d^2 \\ +pe\end{array}\right\} = 0.$$

Whence, if any equation is propoſed, and ſuch values of $a$, $b$, $c$, $d$, $e$, $p$ can be aſſumed as to make *that* equation and *this* coincide, then the *locus* of that equation will be a *parabola*. The conſtruction of which may be deduced from this article.

§ 27. In this general equation for the parabola, the coefficient of $x^2$ is the ſquare of half the coefficient of $xy$; and, "when any equation is propoſed that has this property, the *locus* of it is a *parabola*." For, whatever coefficients affect the three laſt terms, they may be made to agree with the coefficients of the laſt terms of the general equation, by aſſuming proper values of $p$, $c$, and $e$.

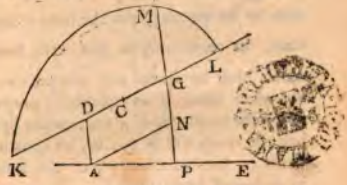
It appears alſo, that "if the locus be a parabola, and the term $xy$ be wanting, the term $x^2$ muſt alſo be wanting." And, "if any equation of two dimenſions be propoſed that

wants

wants both the terms, $xy$ and $x^2$, it may be always accommodated to a *parabola*.

§ 28. The general equation for the *ellipſe* is deduced from the property of the ordinates of any diameter, in the ſame manner; the conſtruction of the figure being the ſame as in § 26. Only, in place of the *parabola*,

Let KML be an *ellipſe* whoſe diameter is KL, having its ordinates parallel to PM, and




let C be the center of the *ellipſe*. Suppoſe CL $= t$, and the *parameter* of that diameter $= p$, then $GMq : CLq - CGq :: p : 2t$. But, as in § 26, $GM = y - \frac{b}{a}x - d$, and $CG = \frac{c}{a}x - e$; therefore, $\overline{y - \frac{b}{a}x - d}^2 \times \frac{2t}{p} = t^2 - \frac{c^2}{a^2}x^2 + \frac{2ce}{a}x - e^2$: whence this equation;

$$y^2 - \frac{2b}{a}xy + \frac{b^2}{a^2}\Big\}x^2 - 2dy + \frac{2bd}{a}\Big\}x + d^2\Big\} - \frac{pt}{2}\Big\} + \frac{pc^2}{2t}\Big\} = 0.$$

And

And if any equation is propoſed that can be made to agree with this general equation, by aſſuming proper values of $a$, $b$, $c$, $d$, $p$ and $e$; then the *locus* of that equation will be an *ellipſe*.

§ 29. "In the general equation for the *ellipſe*, the terms $x^2$ and $y^2$ have the ſame ſign: and the coefficient of $x^2$ is always greater than the ſquare of half the coefficient of $xy$, becauſe $\frac{b^2}{a^2} + \frac{pt^2}{2ta^2}$ is greater than $\frac{b^2}{a^2}$. And although the term $xy$ be wanting, yet the term $x^2$ muſt remain, its coefficient, in that caſe, being $\frac{p}{2t}$, which muſt be always real and poſitive. On the other hand, if an equation is propoſed in which the coefficient of $x^2$ exceeds the ſquare of half the coefficient of $xy$; or, an equation that wants $xy$, but has $x^2$ and $y^2$, of the ſame ſign, its *locus* muſt be an *ellipſe*."

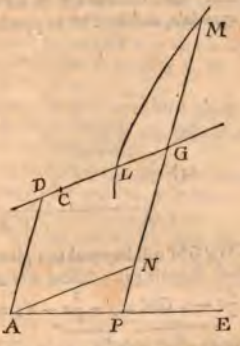
If $t$ be negative.

§ 30. In the hyperbola, as $GM_q : CG_q - CL_q :: p : 2t$; when $t$ is a *firſt* diameter, the equation that ariſes will differ from the equation of the *ellipſe* only in the ſigns of the values of $CG_q$ and $CL_q$, and conſequently will have this form,

$$y^2 - \frac{2b}{a}xy + \frac{b^2}{a^2}x^2 - 2dy + \frac{2bd}{a}x + d^2 \left.\begin{array}{l} \\ \\ \\ \end{array}\right\} = 0.$$
$$- \frac{pc^2}{2ta^2}x^2 \quad + \frac{pce}{at}x + \frac{pt}{2}$$
$$- \frac{pe^2}{2t}$$

If

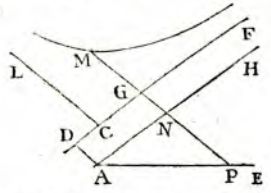
If $t$ be a *second* diameter, then $\frac{pt}{2}$ will be negative.




In this equation, it is manifeſt that the coefficient of the term $x^2$ is leſs than the ſquare of half the coefficient of $xy$; and, that when the term $xy$ is wanting, the term $x^2$ muſt be negative. And, reciprocally, "if an equation is propoſed where the coefficient of $x^2$ is leſs than the ſquare of half the coefficient of $xy$; or where $xy$ is wanting and $y^2$ and $x^2$ have contrary ſigns, the locus of that equation muſt be an *hyperbola*."

§ 31.

§ 31. The equation of the *hyperbola* when its ordinates PM are parallel to an afymptote does not come under the general equation of the laft article. Let CF and CL be the *afymptotes* of the *hyperbola*, and let PM be parallel to CL.



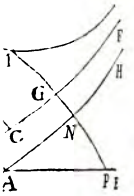

Then CG×GM will be equal to a given rectangle (which fuppofe $ga$). Then, $CG = DG - DC = \frac{c}{a}x - e$, $GM = y - \frac{b}{a}x - d$; and conſequently $\overline{y - \frac{b}{a}x - d} \times \overline{\frac{c}{a}x - e} = g \times a$: whence this equation,,

$$xy - \frac{b}{a}x^2 + \frac{eb}{c}\Big\} x \quad -\frac{ea}{c}y + \frac{eda}{c} \Big\} = 0.$$
$$-d \qquad\qquad -\frac{ga^2}{c}$$

Where only one of the terms $y^2$, $x^2$, can be found with $xy$; and where $xy$ will be found without either of theſe terms, if AE and AH coincide, that is, if AE is parallel to the afymptote DF.

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$$x \left| \begin{array}{l} -\frac{aa}{c}y + \frac{abb}{c} \\ -\frac{gaa}{c} \end{array} \right| = 0.$$

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is parallel to the afymptote

It



It appears from this, that "if an equation is propoſed that either has *xy* the only term of two dimenſions; or, has *xy* and either $x^2$ or $y^2$ beſides, but not both of them, the locus of the equation ſhall be an *hyperbola*, one of whoſe *aſymptotes* ſhall be parallel to *y* or *x* according as it is $y^2$ or $x^2$ that is wanting in the equation."

§ 32. From all theſe compared together, it follows, that "*the* locus *of any equation of two dimenſions is a* conic ſection."

For if the term *xy* is wanting in the equation, and but one of the terms $y^2$, $x^2$ is found in it, the *locus* ſhall be a *parabola*; by § 27.

If *xy* is wanting, and $x^2$, $y^2$, have the ſame ſign, then the *locus* is an *ellipſe*. § 29.—But, when they have different ſigns, it is an *hyperbola*. § 30.

If *xy* is found in the equation, and $x^2$, $y^2$, are both wanting, or either of them, the *locus* is an *hyperbola*. § 31.

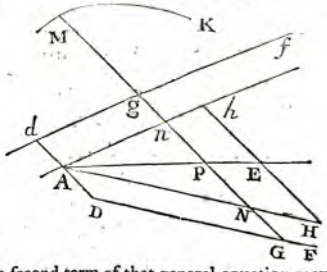
If both $x^2$ and $y^2$ are found in it, having contrary ſigns, the *locus* is ſtill an *hyperbola*.

If $y^2$ and $x^2$ have the ſame ſigns, then, according as the coefficient of $x^2$ is *greater*, *equal*, or *leſs* than the ſquare of half the coefficient of *xy*, the locus ſhall be an *ellipſe*, *parabola*, or *hyperbola*. § 27, 29, 30.

In any caſe therefore the *locus* of the equation is ſome *conic ſection*.

§ 33.

§ 33. Theſe may all be demonſtrated more directly from the conſideration of the general equation of the lines of the *ſecond order* in § 21. For it is obvious that, by § 25. *Part* II.




the ſecond term of that general equation may be exterminated by aſſuming $z = y + \frac{ax+b}{2}$, and it will be transformed into

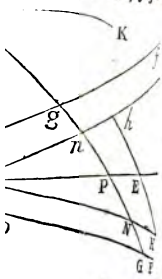
$$\left.\begin{array}{l} z^{2*} + \overline{\frac{4c-a^2}{4} \times x^2} \\ \quad + \overline{d - \frac{ab}{2} \times x} \\ \qquad + e - \frac{b^2}{4} \end{array}\right\} = 0,$$

which, by tranſpoſing the laſt term, is,

$$z^2 = \left.\begin{array}{l} \overline{\frac{a^2}{4} - c \times x^2} + \overline{\frac{ab}{2} - d + x} \\ \qquad + \frac{b^2}{4} - e \end{array}\right\}.$$

Let

may all be demonſtrated in the conſideration of the gene-
e lines of the ſecond order
obvious that, by §25. Rem.




of that general equation $ay^2$
; aſſuming $z = y + \frac{ax+b}{2}$, it
ormed into

$$\left.\begin{array}{l} \frac{-a^2}{4} \times x^2 \\ -\frac{ab}{2} \times x \\ \qquad + t - \frac{b^2}{4} \end{array}\right\} = 0,$$

poſing the laſt term, is,

$$\left.\begin{array}{l} x^2 + \frac{ab}{2} d + x \\ \qquad - t \end{array}\right\} + \frac{b^2}{4}.$$

Le



Let MK be the locus of the equation: and if AH be drawn ſo that HE be to AE as $\frac{1}{2}a$ to unit, and AD, parallel to PM, be $= \frac{1}{2}b$, and through D the line DF be drawn parallel to AH, meeting PM in G, then ſhall GM $(= \text{PM} + \text{PN} + \text{NG} = y + \frac{1}{2}ax + \frac{1}{2}b) = z$. And if $\text{AH} = f$, then $\text{DG} = \text{AN} = fx$.

Suppoſe $\text{DG} = u$, and $x = \frac{u}{f}$. Inſtead of $x$ ſubſtitute $\frac{u}{f}$, and the equation that reſults will expreſs the relation of GM and DG, of this form,

$$z^2 = \frac{a^2 - 4c}{4f^2} \times u^2 + \frac{ab - 2d}{2f} \times u + \tfrac{1}{4}b^2 - e = 0.$$

Which will be an *hyperbola*, *parabola*, or *ellipſis*, according as the term $\frac{a^2-4c}{4f^2}$ is *poſitive*, *nothing*, or *negative*. That is, according as $\frac{a^2}{4}$ is *greater*, *equal* to, or *leſs* than $c$. But $a$ was the coefficient of $xy$; from which it appears, that "the locus is an *ellipſe*, *parabola*, or *hyperbola*, according as the coefficient of $x^2$ is *greater*, *equal* to, or *leſs* than the ſquare of half the coefficient of $xy$."

It appears alſo, that "if the term $xy$ be wanting, or $a = 0$, then the locus will be an *ellipſe*, *parabola*, or *hyperbola*, according as the term $cx^2$ is *poſitive*, *nothing*, or *negative*."

Hence

therefore $BP \times DP = x^2 + \frac{d}{c}x + \frac{e}{c}$. Now, it is manifeſt from the nature of equations, that if PM meet the curve in M and $m$, the rectangle of the roots PM and $Pm$ ſhall be equal to $cx^2 + dx + e$ the laſt term of the equation

$$\left.\begin{matrix} y^2 + axy + cx^2 \\ + by + dx \\ + e \end{matrix}\right\} = 0.$$

We have therefore $PM \times Pm = cx^2 + dx + e$; and $BP \times DP = x^2 + \frac{d}{c}x + \frac{e}{c}$; ſo that $PM \times Pm : BP \times DP :: cx^2 + dx + e : x^2 + \frac{d}{c}x + \frac{e}{c} :: c : 1$. That is, "the rectangle of the ordinates PM, $Pm$ is to the rectangle of the ſegments of the abſciſſes, as, in a given ratio, $c$ is to 1." Which is another general property of the lines of the *ſecond order*.

In a ſimilar manner the analogous properties of the lines of the higher orders are demonſtrated *.

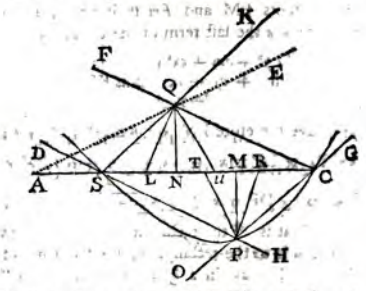
§ 36. There are many different ways of deſcribing the lines of the *ſecond order*, by motion. The following is Sir *Iſaac Newton*'s.

† Let the two points C and S be given, and the ſtraight line AE in the ſame plane. Let the

* See the APPENDIX.
† See *Geometria Organica*, Prop. I.

given

given angles FCO, KSH, revolve about the points C and S as poles, and let the interſection of the ſides CF, SK, be carried along the




ſtraight line AE, and the interſection of the ſides CO, SH, will deſcribe a line of the *ſecond order*.

Let the ſides CF, SK interſect each other in Q, and the ſides CO, SH, in P; let PM and QN be perpendicular on CS. Then draw PR, QU; PT, QL; ſo that CUQ = CRP = FCG; and SLQ = STP = KSD.

The angle RCP = CQU, ſince RCP makes two right ones with RCQ and QUC. So that the triangles CUQ and CRP will be ſimilar. And after the ſame manner you may demon-

ſtrate that the triangles SLQ, STF are ſimilar; whence,

CR : PR :: QU : CU,
and ST : PT :: QL : SL.

Suppoſe CS $= a$, CA $= b$, the ſine of the angle FCO to its coſine as $d$ to $a$; ſin. angle CAE to coſin. as $c$ to $a$, and ſin. KSH to coſin. as $e$ to $a$. Put alſo PM $= y$, CM $= x$, QN $= z$.

Then RM : PM :: $a : d$. PR : PM :: $\sqrt{a^2+d^2} : d$. AN. : QN :: $a : c$. So that RM $= \frac{dy}{a}$, CR (= CM $-$ RM) $= x - \frac{dy}{a}$, PR $= y\frac{\sqrt{a^2+d^2}}{a}$.

Likewiſe QU $= \frac{z\sqrt{a^2+d^2}}{a}$, and CU (= CA $-$ AN $-$ NU) $= b - \frac{a}{c}z - \frac{e}{a}z$. And it being CR : PR :: QU : CU, it follows that $dx - dy : y\sqrt{a^2+d^2} :: z\sqrt{a^2+d^2} : b - \frac{a}{c}z + \frac{e}{a}z$. So that $z = \frac{bc \times dx - dy}{dc - a^2 \times y + d + e \times ax}$.

In like manner you will find ST $= a - x - \frac{a}{e}y$, PT $= \frac{y\sqrt{a^2+e^2}}{e}$, QL $= \frac{z\sqrt{a^2+e^2}}{c+a}$, and SL (= AN $-$ AS $-$ NL) $= a - b + \frac{e-c \times az}{ac}$. But

it

it was ST : PT :: QL : SL, that is, $a-x-\frac{a}{e}y : \frac{y\sqrt{a^2+e^2}}{e} :: \frac{z\sqrt{a^2+e^2}}{s} : a-b+\frac{\overline{e-c}\times az}{ec}$.

Whence $QN=z=\frac{\overline{a-b}\times c\times ae-cx-ey}{\overline{ic+a^2}\times y+ax\times e-c+a^2\times c-e}$.

And from the equation of theſe two values of $z$ this equation reſults;

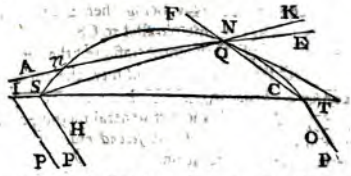
$$\left.\begin{matrix}\overline{a-b}\times ce\\ +\overline{ae-bc}\times d\end{matrix}\right\}x^2+a^2\times\overline{d+c-e}\left\{xy+a\times\overline{-a^2+cd}\right\}y^2$$
$$\left.\begin{matrix}+abc\times\overline{d+e}\\ -a^2e\times\overline{d+c}\end{matrix}\right\}x\left\{\begin{matrix}-bc\times\overline{a^2-cd}\\ -ae\times\overline{dc-a^2}\end{matrix}\right\}y=0;$$

where ſince $x$ and $y$ are only of two dimenſions, it appears that the curve deſcribed muſt be a line of the ſecond *order*, or a conic ſection, according to what has been already demonſtrated.

§ 37. As the angles FCO, KSH revolve about the poles C and S, if the angle CQS becomes equal to the ſupplement of theſe given angles to four right ones, then the angle CPS muſt vaniſh, that is, the lines CO and SH muſt become parallel: and the interſection P muſt go off to an infinite diſtance. And the lines CO and SH become, in that caſe, parallel to one of the *aſymptotes*.

In order to determine if this may be, deſcribe on CS an arc of a circle that can have inſcribed in it an angle equal to the ſupplement of the angles FCO, KSH, to four right angles. If

this arc meet the line AE in two points N, n, then when Q the interſection of the ſides CF, SK comes to either of theſe points, as it is car-




ried along the line AE, the point P will go off to infinity, and the lines SH, CO, become parallel to each other and to an *aſymptote* of the curve.

If that arc only touch the line AE, the point P will go off to infinity but once. If the arc neither cut the line AE nor touch it, the point P cannot go off to infinity. In the firſt caſe the conic ſection is an *hyperbola*, in the ſecond a *parabola*, in the third an *ellipſe*.

The *aſymptotes*, when the curve has any, are determined by the following conſtruction.

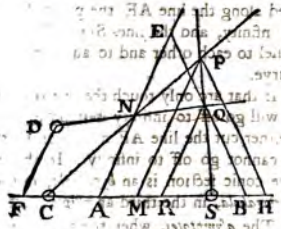
Draw NT conſtituting the angle CNT = SNA, meeting SC in T; then take SI = CT, and always towards oppoſite parts, and through I draw IP parallel to SH or CO, and IP will be one aſymptote of the curve. The other is determined in like manner, by bringing Q to n.

And

And the two aſymptotes meet in the center, conſtituting there an angle = NS*n*.

From this conſtruction it is obvious, that when the circular arc CN*n*S touches the line AE, the angle SNA being then = SCN, the line NT will become parallel to CS; and therefore CT and SI become infinite, that is, the *aſymptote* IP going off to infinity, the curve becomes a *parabola*.

§ 38. There is another general method of deſcribing the lines of the *ſecond order*, that deſerves our conſideration.




Inſtead of angles we now uſe three rulers DQ, CN, SP, which we ſuppoſe to revolve about the poles D, C, S, and cut one another always in three points N, Q and P; and carrying any two of theſe interſections, as N and Q, along the given ſtraight lines AE, BE, the third interſection P will deſcribe a conic ſection.

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Through
PM, QA,
M, R; al
BE meeting
Then pu
$= k$, $SO =$
$AB = a$
PMH, AI
$MH = \frac{y}{a}$,
CA : AN :
SB : BQ ::
BQ : QR
Now A
this to
$\frac{ly}{a} - kl = \frac{}{}$
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and order
$l\sqrt{x^2 + y^2} =$
$+ kaly + k$
In whic
ay vary

and lines; but $x$ and $y$ not riſing to more than two dimenſions, it appears that the point P always deſcribes a *conic ſection*. Only in ſome particular caſes the conic ſection becomes a ſtraight line. As for example, when D is found in the ſtraight line CS; for then DF vaniſhing the terms $d/kx^2 - ad/kx$ vaniſh, and the remaining terms being diviſible by $y$, the equation becomes,

$$\overline{bf \times c-l-f} \times y + \overline{cld - bd} \times \overline{l+f} \times x + \overline{bad} \times \overline{l+f} = 0.$$

Which is a *locus* of the *firſt order*, and ſhews, that, in this caſe, P muſt deſcribe a *ſtraight line*.

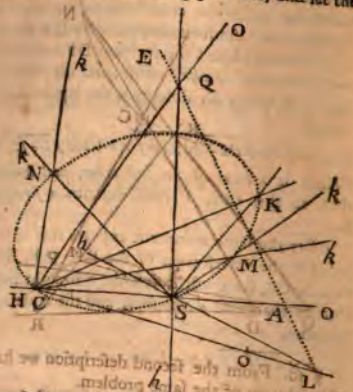
After the ſame manner it appears that if the point E the interſection of the lines AE, BE, falls in CS, then will P deſcribe a ſtraight line. For in that caſe $d$ vaniſhes, and the equation becomes,

$$b \times \overline{c-l-f} \times y - f \times \overline{c-k} \times x = 0.$$

§ 39. Theſe two deſcriptions furniſh, each, a general method of "deſcribing a line of the ſecond order through any five given points whereof three are not in the ſame ſtraight line."

Suppoſe the five given points are C, S, M, K, N; join any three of them, as C, S, K, and let angles revolve about C and S equal to the angles KCS, KSC. Apply the interſection of the legs CK, SK firſt to the point N, and let the inter-

intersection of the legs CO and SH be Q; secondly apply the intersection of the same legs CK, SK, to the remaining point M, and let the

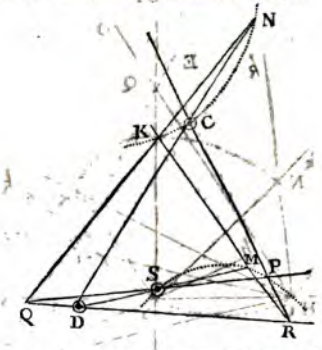



intersection of the legs CO, SH be L. Draw a line joining Q and L, and it will be the line AE along which if you carry the intersection of the legs CO, SH, the intersection of the other legs will describe a conic section passing through the five given points C, S, M, K, N.

It must pass through C and S from the construction: when the intersection of CO, SH comes to A, the curve will pass through K.

And

And when it becomes to Q and L, it paſſes through N, M.




§ 40. From the ſecond deſcription we have this ſolution of the ſame problem.

Let C, S, M, K, N be the five given points: draw lines joining them, produce two of the lines NC, MS, till they meet in D. Let three rulers revolve about the three poles C, S, D, viz. CP, SQ, DR. Let the interſection of the rulers CP, DR, be carried over the given line MK, and the interſection of the rulers SQ, DR be carried through the line NK; and the point P, the interſection of the rulers

that

that revolve about C and S, will deſcribe a conic ſection that paſſes through the five points C, S, M, K, N.

§ 41. It is a remarkable property of the conic ſections, that "if you aſſume any number of poles whatſoever, and make rulers revolve about each of them, and all the interſections but one, be carried along given right lines, that one ſhall never deſcribe a line above a conic ſection;" if, inſtead of rulers you ſubſtitute given angles which you move on the ſame poles, the curve deſcribed will ſtill be no more than a conic ſection.

By carrying one of the interſections neceſſary in the deſcription over a *conic* ſection, lines of higher orders may be deſcribed.

CHAP.

## CHAP. III.

### Of the Conſtruction of *cubic* and *biquadratic* Equations.

42. "THE roots of any equation may be determined by the interſections of a ſtraight line with a curve of the ſame dimenſions as the equation:" or, "by the interſections of any two curves whoſe indices multiplied by each other give a product equal to the index of the propoſed equation."

Thus the roots of a *biquadratic* equation may be determined by the interſections of two conic ſections; for the equation by which the ordinates from the four points in which theſe conic ſections may cut one another can be determined will ariſe to four dimenſions: and the conic ſections may be aſſumed in ſuch a manner, as to make this equation coincide with any propoſed biquadratic: ſo that the ordinates from theſe four interſections will be equal to the roots of the propoſed biquadratic.

If one of the interſections of the conic ſection falls upon the *axis*, then "one of the ordinates vaniſhes, and the equation by which theſe ordinates are determined will then be of three dimenſions only, or a *cubic*," to which any propoſed cubic equation may be accommodated.

So

So that the three remaining ordinates will be the three roots of that propoſed cubic.

§ 43. Thoſe conic ſections ought to be preferred for this purpoſe that are moſt eaſily deſcribed. They muſt not however be both *circles*; for their interſections are only two, and can ſerve only for the reſolution of *quadratic* equations.

Yet the circle ought to be one, as being moſt eaſily deſcribed; and the *parabola* is commonly aſſumed for the other. Their interſections are determined in the following manner.




Let

Let APE be the common Apollonian parabola. Take on its axis the line AB = half of its parameter. Let C be any point in the plane of the parabola, and from it as a center deſcribe, with any radius CP, a circle meeting the parabola in P. Let PM, CD, be perpendiculars on the axis in M and D, and let CN, parallel to the axis, meet PM in N.

Then will always $CP^2 = CN^2 + NP^2$ (47 *ê* 1.)

Put CP = $a$, the parameter of the parabola = $b$, AD = $c$, DC = $d$, AM = $x$, PM = $y$.

Then $CN^2 = \overline{x \mp c}^2$, $NP^2 = \overline{y \mp d}^2$; and $\overline{x \mp c}^2 + \overline{y \mp d}^2 = a^2$*. That is,

$$x^2 \pm 2cx + c^2 + y^2 \pm 2dy + d^2 = a^2.$$

But, from the nature of the parabola, $y^2 = bx$, and $x^2 = \frac{y^4}{b^2}$; ſubſtituting therefore theſe values for $x^2$ and $x$, it will be,

$$\frac{y^4}{b^2} \pm \frac{2cy^2}{b} + y^2 \pm 2dy + c^2 + d^2 - a^2 = 0.$$

Or, multiplying by $b^2$,

$$y^4 \pm \overline{2bc + b^2} \times y^2 \pm 2db^2 \times y + \overline{c^2 + d^2 - a^2} \times b^2 = 0.$$

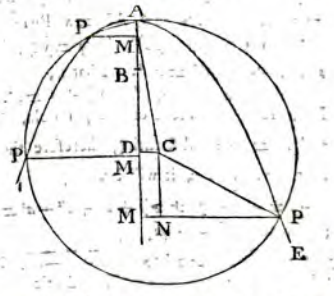
Which may repreſent any biquadratic equation that wants the ſecond term; ſince ſuch values may be found for $a$, $b$, $c$, and $d$, by comparing this with any propoſed biquadratic, as to make them coincide. And then the ordinates from the points P, P, P, P, on the axis will be equal to the roots of that propoſed biquadratic. And

* $x \mp c$ is the differences of $x$ and $c$ indefinitely, whichever of the two is greateſt.

this

this may be done, though the parameter of the parabola *(viz. b)* be given: that is, if you have a parabola already made or given, by it alone you may resolve all biquadratic equations, and you will only need to vary the center of your circle and its radius.

§ 44. If the circle described from the center C pass through the vertex A, then $CP^2 = CA^2 = CD^2 + AD^2$, that is, $a^2 = d^2 + c^2$; and the




last term of the biquadratic $(c^2 + d^2 - a^2)$ will vanish; therefore, dividing the rest by $y$, there arises the cubic,

$$y^3 \pm \overline{2b^2}\,y + \overline{b^2} \times y \pm 2db^2 = 0.$$

Let the cubic equation proposed to be resolved be $y^3 \pm py \pm r = 0$. Compare the terms of these

theſe two equations, and you will have $\pm 2bc + b^2 = \pm p$, and $\pm 2db^2 = \pm r$, or, $\mp c = \frac{b}{2} \mp \frac{p}{2b}$, and $d = \pm \frac{r}{2b^2}$. From which you have this conſtruction of the cubic $y^3 \pm py \pm r = 0$, by means of any given parabola APE.

" *From the point B take in the axis (forward if the equation has* $-p$, *but backwards if* $p$ *is poſitive) the line* $BD = \frac{p}{2b}$; *then raiſe the perpendicular* $DC = \frac{r}{2b^2}$, *and from C, deſcribe a circle paſſing through the vertex A, meeting the paralela in P, ſo ſhall the ordinate PM be one of the roots of the cubic* $y^3 \pm py \pm r = 0$."

The ordinates that ſtand on the ſame ſide of the axis with the center C are negative or affirmative, according to the laſt term $r$ is *negative* or *affirmative*; and thoſe ordinates have always *contrary* ſigns that ſtand on *different* ſides of the *axis*. The roots are found of the ſame value, only they have contrary ſigns, when $r$ is poſitive as when it is negative; the ſecond term of the equation being wanting; which agrees with what has been demonſtrated elſewhere.

§ 45. In reſolving *numerical* equations, you may ſuppoſe the parameter $b$ to be unit; then

AD $= \frac{1}{2} \mp \frac{1}{2}p$, and DC $= \frac{1}{2}r$; and the ordinate PM must then be measured on a scale where the *parameter*, or 2AB is unit. Or, if it be more convenient, the *parameter* may be supposed to express 10, 100, *&c.* or any other number, and PM will be found by measuring it on a scale where the parameter is 10, 100, *&c.* or that other number.

§ 46. "When the circle meets the *parabola* in one point only besides the vertex, the equation has only one real root, and the other two imaginary."

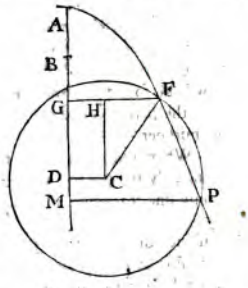
Thus, if the equation has $+p$, or if D falls on the same side of B as A does, the circle can meet the parabola in two points only, whereof A is one; and therefore the equation must have two *imaginary* roots; as we demonstrated elsewhere. If the circle *touch* the *parabola*, then two roots of the equation are equal.

It is also obvious, that the equation must necessarily have *one real* root; because, since the circle meets the *parabola* in the vertex A, it must meet it in one other point, at least, besides A.

§ 47. Instead of making the circle pass thro' the *vertex* A, you may suppose it to pass through some other given point in the parabola, and that intersection being given, the *biquadratic* found for determining the intersections, in § 43, may be reduced to a *cubic*.

Let

Let the ordinate belonging to that given




interſection be $g$, then one of the values of $y$ being $g$, it follows that the biquadratic

$$y^4 \pm 2bc \left.\begin{matrix} \\ + b^2 \end{matrix}\right\} y^2 \pm 2db^2 y + \overline{d^2 + c^2 - a^2} \times b^2 = 0$$

will be diviſible by $y - g$, which will reduce it to a *cubic* that ſhall have the ſecond term. And thus we have a conſtruction for *cubic* equations that have all their terms.

For example, let us ſuppoſe that the *parameter* is AG, and the ordinate at G is GF meeting the curve in F. Suppoſe now that the circle is always to paſs through F; then ſhall $CF_q (= a^2) = CH_q + HF_q = \overline{c \pm b}^2 + \overline{b \pm d}^2 = c^2 + d^2 \pm 2cb \pm 2db + 2b^2$, and ſubſtituting in

in the equation of § 43 this value of $a^2$, it becomes

$$\left.\begin{matrix} y^4 \pm 2cb \\ +b^2 \end{matrix}\right\} y^2 \pm 2db^2 \times y - \left.\begin{matrix} 2b^4 \\ \mp 2cb^2 \\ \mp 2db^3 \end{matrix}\right\} = 0.$$

Where $c$ in the laſt term has a contrary ſign to what it has in the third, and $d$ a contrary ſign to what it has in the fourth.

This biquadratic has FG, or $b$, for one of its roots; and being divided by $y - b$, there ariſes this cubic,

$$\left.\begin{matrix} y^3 + by^2 \pm 2cb \\ +2b^2 \end{matrix}\right\} y \left.\begin{matrix} \pm 2db^2 \\ \pm 2cb^2 \\ +2b^3 \end{matrix}\right\} = 0,$$

having all its terms compleat. If C had been taken on the other ſide of the axis, the ſecond term $by^2$ had been negative.

Let now any cubic equation be propoſed to be reſolved, as $y^3 + py^2 + qy - r = 0$. And, by comparing it with the preceding, you will find

$$\left.\begin{matrix} p = b \\ q = 2b^2 \pm 2bc \\ -r = 2b^3 \pm 2cb^2 \pm 2db^2 \end{matrix}\right\} \text{whence} \left\{\begin{matrix} b = p, \\ \pm c = p - \frac{q}{2p}, \\ d = \frac{q}{2p} + \frac{r}{2p^2}. \end{matrix}\right.$$

*Therefore, to conſtruct the propoſed* cubic *equation* $y^3 + py^2 + qy - r = 0$, *let the parameter of your* parabola *be equal to* $p$, *take, on the axis from the*

*the vertex A, the line* $AD = p - \frac{q}{2p}$, *and raise the perpendicular* $DC = \frac{q}{2p} + \frac{r}{2p^2}$, *and from C describe a circle through F, meeting the parabola in P, so shall the ordinate PM be a root of the equation.*

If the equation proposed is a *literal* equation of this form $y^3 + py^2 + pqy - p^3r = 0$, having all the terms of three dimensions, then this construction will only require $AD = 1 - \frac{1}{2}q$, and $DC = \frac{1}{2}q + \frac{1}{2}r$.

§ 48. If you suppose the parabola to pass through any point F taken any where in the parabola *(vid. Fig. preced.)* and call the ordinate $FG = e$, then $\overline{e - \frac{e^2}{b}}^2 + \overline{e-d}^2 = a^2$, and the general biquadratic may have this form,

$$y^{4*} + 2cb \left.\begin{matrix} \\ + b^2 \end{matrix}\right\} y^2 - 2db^2y + 2ce^2b \left.\begin{matrix} \\ + 2deb^2 \\ - e^4 \\ - e^2b^2 \end{matrix}\right\} = 0.$$

But since $FG = e$ is one of the values of $y$, the equation will be divisible by $y - e$, and the quotient is found to be this *cubic*,

$$y^3 + cy^2 - 2bc \left.\begin{matrix} \\ + b^2 \\ + e^2 \end{matrix}\right\} y \left.\begin{matrix} - 2db^2 \\ - 2ceb \\ + eb^2 \\ + e^3 \end{matrix}\right\} = 0.$$

Which compared with $y^4 + py^3 + pqy - p^2r = 0$, gives FG (or $e$) $= p$, AD $(= c) = \frac{p^2 + b^2 - pq}{2b}$, and DC $= d = \frac{p^2 \times q + r}{2b^2}$. And by this conſtruction the roots of a compleat cubic equation may be found by any parabola whatſoever.

§ 42. It is eaſy to ſee from § 43. how to conſtruct the roots of a biquadratic by any parabola, after the ſecond term is taken away. But "the roots of a biquadratic may be determined by any parabola:" only they cannot be the ordinates on the axis, but "may be equal to the perpendiculars on a line parallel to the axis, meeting the parabola in F, CD in H, and PM in L."

Let FG be an ordinate to the axis in G; and




the reſt remaining as before, let FL $= x$, PL $= y$, the

the parameter $= b$, CP $= a$, FH $= c$, CH $= d$, FG $= e$.

And ſince $PM_q (= \overline{PL + HD}^q) = AM \times b$, therefore $y^2 + 2ey + e^2 = \overline{AG + FL} \times b = \frac{e^2}{b} + x \times b$; and conſequently $y^2 + 2ey = bx$.

But $CN_q + NP_q = CP_q$; that is, $\overline{x - c}^2 + \overline{y - d}^2 = a^2$. And ſubſtituting for $x^2$ and $x$ their values $\frac{\overline{y^2 + 2ey}^2}{b^2}$ and $\frac{y^2 + 2ey}{b}$; you will find

$$y^4 + 4ey^3 + \left.\begin{matrix} 4e^2 \\ -2cb \\ +b^2 \end{matrix}\right\} y^2 + \left.\begin{matrix} -4ecb \\ -2db^2 \end{matrix}\right\} y + \left.\begin{matrix} +c^2b^2 \\ +d^2b^2 \\ +a^2b^2 \end{matrix}\right\} = 0,$$

which is a complete biquadratic equation. And by comparing with it the equation $y^4 + py^3 + bqy^2 - b^2ry - b^3s = 0$, you will find FG $(= e) = \frac{1}{4}p$, FH $(= c) = \frac{\frac{1}{4}p^2 + b^2 - bq}{2b}$, HC $(= d) = \frac{b^2r - pbc}{2b^2}$, and CP $(= a) = \sqrt{b^2s + c^2 + d^2}$: which gives a general conſtruction for any ſuch biquadratic equation by any parabola whatſoever. If the ſigns of $p$, $q$, $r$, or $s$, are different, it is eaſy to make the neceſſary alterations in the conſtruction. *Ex. gr.* If $p$ is negative, then FG muſt be taken on the other ſide of the axis.

If you ſuppoſe the circle to paſs through F, the equation will become a *cubic* having all its

terms: the laſt term $c^2 + d^2 - a^2 \times b^2$ vaniſhing, becauſe then $c^2 + d^2 = a^2$. It will have this form,

$$y^4 + 4cy^3 + 4c^2 \left.\begin{matrix} \\ -2cb \\ +b^2 \end{matrix}\right\} y^2 \left.\begin{matrix} -4ecb \\ -2db^2 \end{matrix}\right\} = 0;$$

and then "the conſtruction will give the roots of a compleat cubic equation."

§ 50. We have ſufficiently ſhewed, how the roots of cubic and biquadratic equations may be conſtructed by the parabola and circle; we ſhall now ſhew how *other* conic ſections may be determined by whoſe interſections the ſame roots may be diſcovered.

Let the equation propoſed be $y^4 + bpy^2 + b^2qy - b^3r = 0$; and let us ſuppoſe, that,

1°. $bx = y^2$; then ſhall we have by ſubſtitution of $b^2x^2$ for $y^4$, and dividing by $bp$,

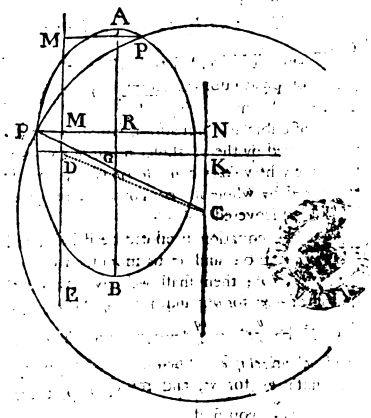
2°. $y^2 + \frac{b}{p}x^2 + \frac{bq}{p}y - \frac{b^2r}{p} = 0$, which has its *locus* an *ellipſe*. Then by ſubſtituting (in this laſt) $bx$ for $y^2$, and multiplying all the terms by $\frac{p}{b}$, you find,

3°. $x^2 + px + qy - br = 0$, an equation to a *parabola*. Then, adding to this equation $y^2 - bx = 0$, you will have,

4°. $x^2 + y^2 \left.\begin{matrix} \\ +p \\ -b \end{matrix}\right\} x + qy - br = 0$, an equation to a *circle*.

The

The roots of the equation $y^{4n} + bpy^2 + b^2qy - b^3r = 0$ may be determined by the interfection of any *two* of theſe *loci*; as for example,




by the interfections of the *ellipſe* that is the *locus* of the equation $y^2 + \frac{b}{p}x^2 + \frac{b^2}{p}y - \frac{b^3r}{p} = 0$, and of the *circle* which is the *locus* of $x^2 + y^2 \mp_{b}^{p}\}x + qy - br = 0$, from which we deduce this conſtruction.

*Let*

*Let AB be the axis of an ellipſis, equal to* $\sqrt{br+\frac{bq^2}{4p}}$, *let G be the center of the ellipſe, and the axis to the parameter as p to b. At G, raiſe a perpendicular to the axis, and on it take* $GD=\frac{bq}{2p}$, *and on the other ſide in the perpendicular continued take* $GK=\frac{1}{2}q\times\frac{p-b}{p}$. *Let DE and KC be parallel to the axis: take* $KC=\frac{1}{2}b-\frac{1}{2}p$, *and from C as a center, with the radius* $\sqrt{DCq+br}$ *deſcribe a circle meeting the ellipſe in P, and the ordinate PM, on the line DE, ſhall be one of the roots of the propoſed equation.*

Let PM ($=y$) produced meet AB in R, and KC in N; and calling $DM=x$, then $CPq=NPq+NCq$, that is, $\frac{1}{4}q^2+\frac{1}{4}b^2-\frac{1}{2}pb+\frac{1}{4}p^2+br=\overline{\frac{1}{2}b-\frac{1}{2}p-x}^2+\overline{y+\frac{1}{2}q}^2$; and therefore,

1°. $y^2+x^2+qy\left.\begin{matrix}-b\\+p\end{matrix}\right\}x-br=0$, the equation to the circle, which was to be conſtructed.

And ſince $PRq:GBq-GRq::b:p$, therefore $\overline{y+\frac{bq}{2p}}^2:br+\frac{bq^2}{4p}-x^2::b:p$; and conſequently,

2°. $y^2+\frac{b}{p}x^2+\frac{bq}{p}y-\frac{b^2r}{p}=0$; which is the equation that was to be conſtructed.

Now that their interſections will give the roots required, appears thus.

For

For $x^2$ in the firſt equation ſubſtitute the value you deduce for it from the ſecond, *viz.* $br - \frac{p}{b}y^2 - qy$, and there will ariſe

$y^3 - \frac{p}{b}y^2 - \frac{b}{+p}\Big\}x = 0$, or $\frac{b-p}{b} \times y^2 = \overline{b-p} \times x$,

that is, $\frac{y^2}{b} = x$, and $x^2 = \frac{y^4}{b^2}$; which ſubſtituted for $x^2$ and $x$ in the firſt equation, gives

$\frac{y^4}{b^2} + y^2 + \overline{p-b} \times \frac{y^2}{b} + qy - br = 0$; that is, $y^{4} + bpy^2 + b^2qy - b^2r = 0$.

And if you ſubſtitute them in the ſecond equation, there will ariſe

$\frac{b}{b^2}y^4 + y^2 + \frac{bq}{p}y - \frac{b^2r}{p} = 0$, that is, $y^4 + bpy^2 + b^2qy - b^2r = 0$, the very ſame as before; and thus it appears that the roots of the equation $y^4 - bpy^2 + b^2qy - b^2r = 0$ are the ordinates that are common to the *circle* and *ellipſis*, or that are drawn from their interſection.

*End of the* THIRD PART.

APPEN-

# APPENDIX:

DE

Linearum Geometricarum

Proprietatibus generalibus

TRACTATUS.

# DE
# LINEARUM GEOMETRICARUM
## Proprietatibus generalibus.

DE lineis ſecundi ordinis, ſive ſectionibus conicis, ſcripſerunt uberrime geometræ veteres & recentiores; de figuris quæ ad ſuperiores linearum ordines referuntur pauca & exilia tantum ante NEWTONUM tradiderunt. Vir illuſtriſſimus, in Tractatu de *Enumeratione Linearum tertii Ordinis*, doctrinam hanc, cum diu jacuiſſet, excitavit, dignamque eſſe in qua elaborarent geometræ oſtendit. Expoſitis enim harum linearum proprietatibus generalibus, quæ vulgatis ſectionum conicarum affectionibus ſunt adeo affines ut velut ad eandem normam compoſitæ videantur, alios ſuo exemplo impulit ut analogiam hanc ſive ſimilitudinem quæ tam diverſis intercedit figurarum generibus bene cognitam & ſatis firme animo conceptam atque comprehenſam habere ſtuderent. In qua illuſtranda & ulterius indaganda curam operamque merito poſuerunt; cum nihil ſit omnium quæ in diſciplinis purè mathematicis tractantur quod pulchrius dicatur aut ad animum veri inveſtigandi cupidum oblectandum aptius, quam rerum tam diverſarum conſenſus ſive harmonia, ipſiuſque doctrinæ compoſitio & nexus admirabilis, quo poſterius priori convenit, quod ſequitur ſuperiori reſpondet,

quæque ſimpliciora ſunt ad magis ardua viam conſtanter aperiunt.

Linearum tertii ordinis proprietates generales a *Newtono* traditæ parallelarum ſegmenta & aſymptotos pleræque ſpectant. Alias harum affectiones quaſdam diverſi generis breviter indicavimus in tractatu de fluxionibus nuper edito, Art. 324, & 401. Celeberrimus *Cotesius* pulcherrimam olim detexit linearum geometricarum proprietatem, hucuſque ineditam, quam abſque demonſtratione nobis communicavit vir Reverendus D. *Robertus Smith*, Collegii S. S. Trinitatis apud Cantabrigienſes Præfectus, doctrina operibuſque ſuis pariter ac fide & ſtudio in amicos clarus. De his meditantibus nobis alia quoque ſe obtulerunt theoremata generalia; quæ cum ad arduam hanc geometriæ partem augendam & illuſtrandam conducere viderentur, ipſa quaſi in faſciculum congerenda & una ſerie breviter exponenda & demonſtranda putavimus.

## SECTIO I.

### *De Lineis Geometricis in genere.*

§ 1. LIneæ ſecundi ordinis ſectione ſolidi geometrici, coni ſcilicet, definiuntur, unde earum proprietates per vulgarem geometriam optime derivantur. Verum diverſa eſt ratio figurarum quæ ad ſuperiores linearum ordines referuntur. Ad has definiendas, earumque proprietates eruendas, adhibendæ ſunt æquationes generales co-ordinatarum relationem exprimentes. Repræſentet $x$ abſciſſam AP, $y$ ordinatam PM figuræ FMH, denotentque $a, b, c, d, e,$ &c. coefficientes quaſcunque

Fig. 1.

inva-

invariabiles; & dato angulo APM si relatio co-ordinatarum $x$ & $y$ definiatur æquatione quæ, præter ipsas coordinatas, solas involvat coefficientes invariabiles, linea FMH geometrica appellatur; quæ quidem auctoribus quibusdam linea algebraica, aliis linea rationalis dicitur. Ordo autem lineæ pendet ab indice altissimo ipsius $x$ vel $y$ in terminis æquationis a fractionibus & surdis liberatæ, vel a summa indicis utriusque in termino ubi hæc summa prodit maxima. Termini enim $x^2$, $xy$, $y^2$ ad secundum ordinem pariter referuntur; termini $x^3$, $x^2y$, $xy^2$, $y^3$ ad tertium. Itaque æquatio $y = ax + b$, sive $y - ax - b = 0$, est primi ordinis & designat lineam sive locum primi ordinis, quæ quidem semper recta est. Sumatur enim Fig. 2. in ordinata PM recta PN ita ut PN sit ad AP ut $+a$ ad unitatem; constituatur AD parallela ordinatæ PM æqualis ipsi $+b$, & ducta DM parallela rectæ AN erit locus cui æquatio proposita respondebit. Nam $PM = PN + NM = (a \times AP + AD)\ ax + b$. Quod si æquatio sit formæ $y = ax - b$ vel $y = -ax + b$, recta AD, vel PN, sumenda est ad alteram partem abscissæ AP; contrarius enim rectarum situs contrariis coefficientium signis respondet. Si valores affirmativi ipsius $x$ designent rectas ad dextram ductas a principio abscissæ A, valores negativi denotabunt rectas ab eodem principio ad sinistram ductas; & similiter si valores affirmativi ipsius $y$ ordinatas repræsentent supra abscissam constitutas, negativi designabunt ordinatas infra abscissam ad oppositas partes ductas.

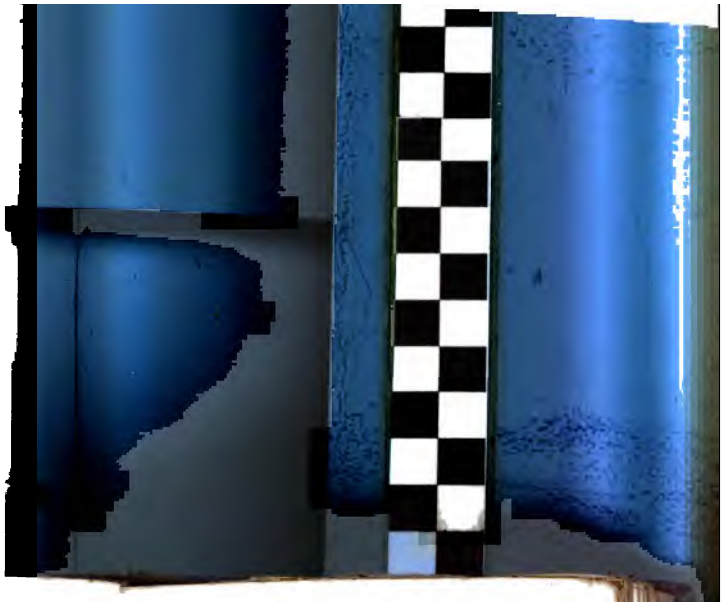
Æquatio generalis ad lineam secundi ordinis est hujus formæ

$$\begin{array}{l} yy - axy + cx^2 = 0 \\ \quad - by - dx \\ \quad + e \end{array}$$

& æquatio generalis ad lineas tertii ordinis eſt $y^3 - \overline{ax+b} \times y^2 + \overline{cxx-dx+e} \times y - fx^3 + gx^2 - hx + k = 0$. Et ſimilibus æquationibus definiuntur lineæ geometricæ ſuperiorum ordinum.

§ 2. Linea geometrica occurrere poteſt rectæ in tot punctis quot ſunt unitates in numero qui æquationis vel lineæ ordinem deſignat, & nunquam in pluribus. Occurſus curvæ & abſciſſæ AP definiuntur ponendo $y=0$, quo in caſu reſtat tantum ultimus æquationis terminus quem $y$ non ingreditur. Linea tertii ordinis *ex. gr.* occurrit abſciſſæ AP cum $fx^3 - gx^2 + hx - k = 0$, cujus æquationis ſi tres radices ſint reales abſciſſa ſecabit curvam in tribus punctis. Similiter in æquatione generali cujuſcunque ordinis index altiſſimus abſciſſæ $x$ æqualis eſt numero qui lineæ ordinem deſignat, ſed nunquam major, adeoque is eſt numerus maximus occurſuum curvæ cum abſciſſa vel alia quavis rectâ. Cum autem æquationis cubicæ unica ſaltem radix ſit ſemper realis, idemque conſtet de æquatione quavis quinti aut imparis cujuſvis ordinis (quoniam radix quævis imaginaria aliam neceſſario ſemper habet comitem), ſequitur lineam tertii aut imparis cujuſcunque ordinis rectam quamvis aſymptoto non parallelam in eodem plano ductam in uno ſaltem puncto neceſſario ſecare. Si vero recta ſit aſymptoto parallela, in hoc caſu vulgo dicitur curvæ occurrere ad diſtantiam infinitam. Linea igitur imparis cujuſcunque ordinis duo ſaltem habet crura in infinitum progredientia. Æquationis autem quadraticæ vel paris cujuſvis ordinis radices omnes nonnunquam fiunt imaginariæ, adeoque fieri poteſt ut recta in plano lineæ paris ordinis ducta eidem nullibi occurrat.

§ 3.





lineas tertii ordinis et /-
$+ e \times y - fx^2 + g^2 - h$
ionibus definiuntur lin
num.

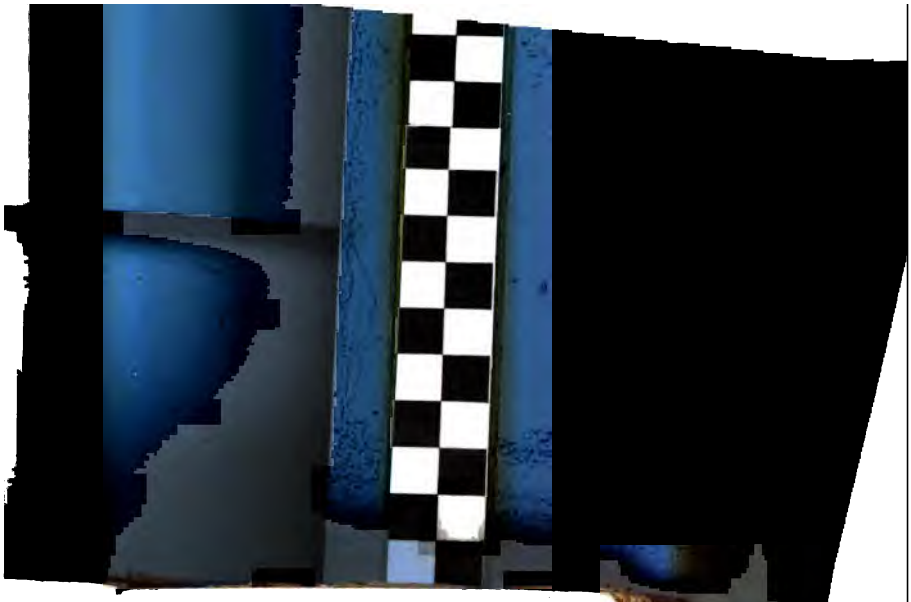
. occurrere potest recta
s in numero qui aequat
& n- aequam in plurib
AP definiuntur potest
ultimus aequationis
Linea tertii ordinis
$fx^3 - gx^2 + hx - l = 0$
sint reales abscissa
similiter in aequatione
altissimus abscissæ
m designat, sed nonnu
us maximus occurrat
ris rectâ. Cum autem
n radix sit semper re
quavis quinti ordinis
radix quævis imaginaria
omitem), sequitur lineas
ordinis rectam quatuor
dem plano ductam in
care. Si vero recta sit
su vulgo dicitur curva
m. Linea igitur impar
habet crura in infinitum
autem quadratice vel
es nonnunquam finis
t ut recta in plano
ibi occurrat.

§ 3. Æquatio secundi aut superioris cujuscunque ordinis quandoque componitur ex tot simplicibus, a surdis & fractis liberatis, in se mutuo ductis quot sunt ipsius æquationis propositæ dimensiones; quo in casu figura FMH non est curvilinea sed conflatur ex totidem rectis, quæ per simplices has æquationes definiuntur ut in *Art.* 1. Similiter si æquatio cubica componatur ex æquationibus duabus in se mutuo ductis, quarum altera sit quadratica altera simplex, locus non erit linea tertii ordinis proprie sic dicta, sed sectio, conica cum rectâ adjunctâ. Proprietatis autem quæ de lineis geometricis superiorum ordinum generaliter demonstrantur, affirmandæ sunt quoque de lineis inferiorum ordinum, modo numeri harum ordines designantes simul sumpti numerum compleant qui ordinem dictæ superioris lineæ denotat. Quæ de lineis tertii ordinis *(ex. gr.)* generaliter demonstrantur affirmanda quoque sunt de tribus rectis in eodem plano ductis, vel de sectione conica cum unica quavis recta simul in eodem plano descriptis. Ex altera parte, vix ulla assignari potest proprietas lineæ ordinis inferioris satis generalis cui non respondeat affectio aliqua linearum ordinum superiorum. Has autem ex illis derivare non est cujusvis diligentiæ. Pendet hæc doctrina magna est parte a proprietatibus æquationum generalium, quas hic memorare tantum convenit.

§ 4. In æquatione quacunque coefficiens secundi termini æqualis est excessui quo summa radicum affirmativarum superat summam negativarum; & si desit hic terminus, indicio est summas radicum affirmativarum & negativarum, vel summas ordinatarum ad diversas partes abscissæ constitutarum, æquales esse. Sit æquatio generalis ad lineam ordinis *n*,

$y^n - \overline{ax+b} \times y^{n-1} + \overline{cxx-dx+e} \times y^{n-2} - \&c. = 0$, ſupponatur $u = y - \frac{ax+b}{n}$, pro $y$ ſubſtituatur ipſius valor $u + \frac{ax+b}{n}$; & in æquatione transformata deerit ſecundus terminus $u^{n-1}$; ut ex calculo, vel ex doctrinâ æquationum paſſim traditâ facile patet: & hinc quoque conſtat, quod per hypotheſim valor quiſque ipſius $u$ minor fit valore correſpondente ipſius $y$ differentia $\frac{ax+b}{n}$; unde ſequitur ſummam valorum ipſius $u$ (quorum numerus eſt $n$) deficere a ſumma valorum ipſius $y$ (quæ ſumma eſt $ax+b$) differentia $\frac{ax+b}{n} \times n = ax + b$, adeoque priorem ſummam evaneſcere & ſecundum terminum deeſſe in æquatione qua $u$ definitur, vel affirmativos & negativos valores ipſius $u$ æquales ſummas conficere. Si itaque ſumatur $PQ = \frac{ax+b}{n}$, ut ſit $QM = u$, rectæ ex utraque parte puncti Q ad curvam terminatæ eandem conficient ſummam. Locus autem puncti Q eſt recta BD quæ abſciſſam ultra principium A productam ſecat in B ita ut $AB = \frac{b}{a}$, & ordinatam AD ipſi PM parallelam in D ita ut ſit $AD = \frac{1}{n} \times b$; ſi enim hæc recta ordinatæ PM occurrat in puncto Q, erit PQ ad PB (ſeu $\frac{b}{a} + x$) ut AD ad AB vel $a$ ad $n$, adeoque $PQ = \frac{ax+b}{n}$, ut oportebat. Atque hinc conſtat rectam ſemper duci poſſe quæ parallelas quaſvis lineæ geometricæ occurrentes in tot punctis quot ſunt figuræ dimenſiones ita ſecabit ut ſumma ſegmentorum cujuſvis paral-

Fig. 3.



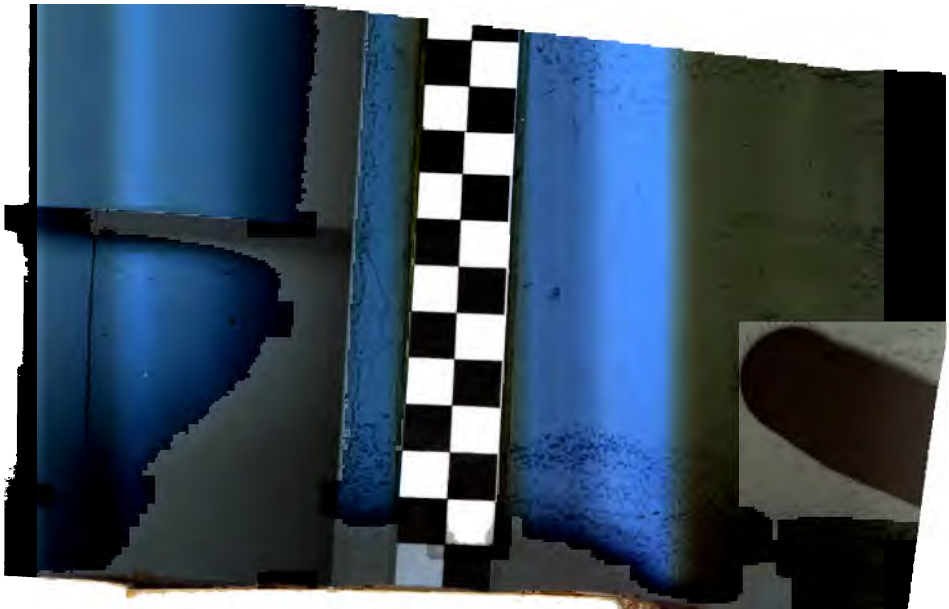


parallelæ ex una ſecantis parte ad curvam terminatorum ſemper æqualis ſit ſummæ ſegmentorum ejuſdem ex altera ſecantis parte. Manifeſtum autem eſt rectam quæ duas quaſvis parallelas hac ratione ſecat ipſam neceſſario eſſe quæ ſimiliter alias omnes parallelas ſecabit. Atque hinc patet veritas theorematis *Newtoniani*, quo continetur proprietas linearum geometricarum generalis, notiſſimæ ſectionum conicarum proprietati analoga. In his enim recta quæ duas quaſvis parallelas ad ſectionem terminatas biſecat diameter eſt, & biſecat alias omnes hiſce parallelas ad ſectionem terminatas. Et ſimiliter recta quæ duas quaſvis parallelas lineæ geometricæ occurrentes in tot punctis quot ipſa eſt dimenſionum ita ſecat ut ſumma partium ex uno ſecantis latere conſiſtentium & ad curvam terminatarum æqualis ſit ſummæ partium ejuſdem parallelæ ex altero ſecantis latere conſiſtentium ad curvam terminatarum, eodem modo ſecabit alias quaſvis rectas his parallelas.

§ 5. In æquatione quavis terminus ultimus, ſive is quem radix $y$ non ingreditur, æqualis eſt facto ex radicibus omnibus in ſe mutuo ductis; unde ad aliam ducimur non minus generalem linearum geometricarum proprietatem. Occurrat recta PM lineæ tertii ordinis in M, $m$ & $\mu$, eritque $PM \times Pm \times P\mu = fx^3 - gx^2 + hx - k$. Secet abſciſſa AP curvam in tribus punctis I, K, L; & AI, AK, AL erunt valores abſciſſæ $x$, poſita ordinata $y = 0$, quo in caſu æquatio generalis dat $fx^3 - gx^2 + hx - k = 0$ pro his valoribus determinandis, ut in Art. 2. expoſuimus. Fig. 1. Æquationis igitur $x^3 - \frac{gx^2}{f} + \frac{hx}{f} - \frac{k}{f} = 0$ tres radices ſunt AI, AK, AL; adeoque hæc æquatio componitur ex tribus $x - AI$, $x - AK$, $x - AL$ in

se mutuo ductis; estque $x^3 - \frac{gx^2}{f} + \frac{hx}{ff} - \frac{k}{f} =$ $\overline{x-AI} \times \overline{x-AK} \times \overline{x-AL} = \overline{AP-AI} \times \overline{AP-AK} \times \overline{AP-AL} = IP \times KP \times LP = \frac{1}{f} \times PM \times Pm \times P\mu$. Factum igitur ex ordinatis PM, $Pm$, $P\mu$ ad punctum P & curvam terminatis est ad factum ex segmentis IP, KP, LP, rectæ AP, eodem puncto & curva terminatis in ratione invariabili coefficientis $f$ ad unitatem. Simili ratione demonstratur, dato angulo APM, si rectæ AP, PM, lineam geometricam cujusvis ordinis secent in tot punctis quot ipsa est dimensionum, fore semper factum ex segmentis prioris ad punctum P & curvam terminatis ad factum ex segmentis posterioris eodem puncto & curva terminatis in ratione invariabili.

§ 6. In articulo præcedente supposuimus, cum *Newtono*, rectam AP lineam tertii ordinis secare in tribus punctis I, K, L; verum ut theorema egregium reddatur generalius, supponamus abscissam AP in unico tantum puncto curvam secare; sitque id punctum A. Fig. 4. Quoniam igitur evanescente $y$ evanescat quoque $x$, ultimus æquationis terminus, in hoc casu, erit $fx^3 - gx^2 + hx = fx \times xx - \frac{gx}{f} + \frac{hb}{ff} = fx \times \overline{x - \frac{g^2}{2f} + \frac{b}{f} - \frac{gg}{4ff}}$ (si sumatur Aa versus P æqualis $\frac{g}{2f}$, & ad punctum $a$ erigatur perpendicularis $ab = \frac{\sqrt{4fb - gg}}{2f}$) $= f \times AP \times \overline{aP^2 + ab^2} = f \times AP \times bP^2$; unde cum PM × $Pm$ × $P\mu$, sit æqualis ultimo termino $fx^3 - gx^2 + hx$, ut





ut in articulo præcedente; erit PM × P*m* × P$\mu$ ad AP × *b*P³ in ratione conſtante coefficientis *f* ad unitatem. Valor autem rectæ perpendicularis *ab* eſt ſemper realis quoties recta AP curvam in unico puncto ſecat; in hoc enim caſu radices æquationis quadraticæ $fx^2 - gx + b$ ſunt neceſſario imaginariæ, adeoque $4fb$ major quam $gg$, & quantitas $\sqrt{4fb - gg}$ realis. Cum igitur recta quævis in unico puncto A ſecat lineam tertii ordinis, eſt ſolidum ſub ordinatis PM, P*m*, P$\mu$ ad ſolidum ſub abſciſſa AP & quadrato diſtantiæ puncti P a puncto dato *b* in ratione conſtanti. Junctæ A*b* eſt ad A*a*, ſive radius ad coſinum anguli *b*AP, ut $\sqrt{4fb}$ ad *g*, & $Ab = \sqrt{\frac{b}{f}}$. Idem vero punctum *b* ſemper convenit eidem rectæ AP, qualiſcunque ſit angulus qui abſciſſa & ordinata continetur.

§ 7. Sit figura ſectio conica, cujus æquatio generalis ſit $yy - \overline{ax - b} \times y + cxx - dx + e = 0$ ut ſupra; & ſi æquationis $cxx - dx + e = 0$ radices ſint imaginariæ, recta AP ſectioni non occurret. In hoc autem caſu quantitas $4ec$ ſemper ſuperat ipſam $dd$; unde cum ſit $cxx - dx + e = c \times x - \frac{d}{2c}^2 + e - \frac{dd}{4c}$ (ſi ſumatur $Aa = \frac{d}{2c}$ & erigatur *ab* perpendicularis abſciſſæ in *a* ita ut $ab = \frac{\sqrt{4ec - dd}}{2c}$) $= c \times \overline{aP^2 + ab^2} = c \times bP^2$, ſitque PM × P*m* = $cxx - dx + e$, erit PM × P*m* ad $bP^2$ ut *c* ad unitatem. Itaque in ſectione quavis conica ſi recta AP ſectioni non occurrat, erit, dato angulo APM, rectangulum contentum ſub rectis ad punctum B conſiſtentibus & ad curvam terminatis ad quadra- Fig. 5.

tum diſtantiæ puncti P a puncto dato *b* in ratione conſtanti, quæ in circulo eſt ratio æqualitatis. Manifeſtum autem eſt eandem methodum adhiberi poſſe lineæ quarti ordinis quam abſciſſa ſecat in duobus tantum punctis, vel lineæ ordinis cujuſcunque quam abſciſſa ſecat in punctis binario paucioribus numero qui figuræ ordinem deſignat.

§ 8. Hiſce præmiſſis, progredimur ad linearum geometricarum proprietates minus obvias exponendas eodem fere ordine quo ſe nobis obtulerunt. Utebamur autem lemmate ſequenti ex fluxionum doctrina petito, quodque in tractatus de hiſce nuper editi Art. 717. demonſtravimus; harum tamen aliquas per algebram vulgarem demonſtrari poſſe poſtea obſervavimus.

*Lemma.* Si quantitatibus $x, y, z, u,$ &c. ſimul fluentibus, ut & quantitatibus $X, Y, Z, V,$ &c. ſit factum ex prioribus ad factum ex poſterioribus in ratione conſtanti quacunque, erit $\frac{\dot{x}}{x} + \frac{\dot{y}}{y} + \frac{\dot{z}}{z} + \frac{\dot{u}}{u} +$ &c. $= \frac{\dot{X}}{X} + \frac{\dot{Y}}{Y} + \frac{\dot{Z}}{Z} + \frac{\dot{V}}{V} +$ &c. Porro, brevitatis gratia, quantitates appellamus ſibi mutuo *reciprocas*, quarum in ſe mutuo ductarum factum eſt unitas, ſic $\frac{1}{x}$ dicimus *reciprocam* eſſe ipſius $x$, & $\frac{1}{y}$ ipſius $y$.

§ 9. Theor. I. *Occurrat recta quævis per punctum datum ducta lineæ geometricæ cujuſcunque ordinis in tot punctis quot ipſa eſt dimenſionum; rectæ figuram in his punctis contingentes abſcindant ab alia rectâ poſitione data per idem punctum datum ductâ ſegmenta totidem hoc punctо terminata; & harum ſegmentorum* reciproca *eandem*

*dem ſemper conficiant ſummam, modo ſegmenta ad contrarias partes puncti dati ſita contrariis ſignis affician-tur.*

Sit P punctum datum, PA & P*a* rectæ quævis duæ ex P ductæ quarum utraque curvam ſecat in tot punctis A, B, C, et *a*, *b*, *c*, &c. quot ipſa eſt dimenſionum. Abſcindant tangentes AK, BL, CM, &c. et *ak*, *bl*, *cm*, &c. a recta EP per punctum datum P ducta ſegmenta PK, PL, PM, &c. et P*k*, P*l*, P*m*, &c. dico fore $\frac{1}{PK}+\frac{1}{PL}+\frac{1}{PM}+$ &c. $=\frac{1}{Pk}+\frac{1}{Pl}+\frac{1}{Pm}+$ &c. atque hanc ſummam manere ſemper eandem manente puncto P & recta PE poſitione data. Fig. 6.

Supponamus enim rectas ABC, *abc* motibus ſibi parallelis deferri, ita ut earum occurſus P progrediatur in recta PE poſitione data; cumque ſit ſemper AP × BP × CP × &c. ad *a*P × *b*P × *c*P in ratione conſtanti per Art. 5. repræſentet $A\dot{P}$ fluxionem ipſius AP, $B\dot{P}$ fluxionem rectæ BP, & $C\dot{P}$, $E\dot{P}$, &c. fluxiones rectarum CP, EP, &c. reſpectivas, ut vitetur inutilis ſymbolorum multiplicatio, eritque (per Art. 8.) $\frac{A\dot{P}}{AP}+\frac{B\dot{P}}{BP}+\frac{C\dot{P}}{CP}+$ &c. $=\frac{a\dot{P}}{aP}+\frac{b\dot{P}}{bP}+\frac{c\dot{P}}{cP}+$ &c. Verum cum recta AP motu ſibi ſemper parallelo deferatur, notiſſimum eſt $A\dot{P}$ fluxionem rectæ AP eſſe ad $E\dot{P}$ fluxionem rectæ EP ut AP ad ſubtangentem PK, adeoque $\frac{A\dot{P}}{AP}=\frac{E\dot{P}}{PK}$. Similiter $\frac{B\dot{P}}{BP}=\frac{E\dot{P}}{PL}$, $\frac{C\dot{P}}{CP}=\frac{E\dot{P}}{PM}$, $\frac{a\dot{P}}{aP}=\frac{E\dot{P}}{Pk}$, $\frac{b\dot{P}}{bP}=\frac{E\dot{P}}{Pl}$ & $\frac{c\dot{P}}{cP}=\frac{E\dot{P}}{Pm}$, unde $\frac{E\dot{P}}{PK}+\frac{E\dot{P}}{PL}+$

$$+\frac{E\dot{P}}{PM}+\&c.=\frac{E\dot{P}}{P\ell}+\frac{E\dot{P}}{Pl}+\frac{E\dot{P}}{Pm}+\&c.\text{ et }\frac{1}{PK}+\frac{1}{PL}+\frac{1}{PM}+\&c.=\frac{1}{P\ell}+\frac{1}{Pl}+\frac{1}{Pm}+\&c.$$

Hæc ita ſe habent quoties puncta K, L, M, &c. et *k*, *l*, *m*, &c. ſunt omnia ad eaſdem partes puncti P, adeoque fluxiones rectarum AP, BP, CP, &c. *a*P, *b*P, *c*P, &c. omnes ejuſdem ſigni. Si vero, cæteris manentibus, puncta quævis M et *m* cadant ad contrarias partes puncti P, tum creſcentibus reliquis ordinatis AP, BP, &c. neceſſario minuuntur ordinatæ CP & *c*P, earumque fluxiones pro ſubdititiis ſeu negativis habendæ ſunt; adeoque in hoc caſu $\frac{1}{PK}+\frac{1}{PL}-\frac{1}{PM}$, &c. $=\frac{1}{P\ell}+\frac{1}{Pl}-\frac{1}{Pm}$, &c. & generaliter in ſummis hiſce colligendis, termini iiſdem vel contrariis ſignis affici-endi ſunt, prout ſegmenta cadunt ad eaſdem vel ad contrarias partes puncti dati P. Fig. 7.

§ 10. Si recta PE occurrat curvæ in tot punctis D, E, I, &c. quot ipſa eſt dimenſionum, ſumma $\frac{1}{PK}+\frac{1}{PL}+\frac{1}{PM}+\&c.$ quam conſtantem ſeu invariatam manere oſtendimus, æqualis erit ſummæ ſeu aggregato $\frac{1}{PD}+\frac{1}{PE}+\frac{1}{PI}+\&c.$ i. e. ſummæ reciprocarum ſegmentis rectæ PE poſitione datæ puncto dato P & curva terminatis; in qua, ſi ſegmentum quodvis ſit ad alteras partes puncti P, hujus reciproca ſubducenda eſt.

§ 11.

$$\frac{E\dot{P}}{P\dot{L}} + \frac{E\dot{P}}{P\dot{l}} + \frac{E\dot{P}}{P\dot{m}} + \&c.$$

$$\&c. = \frac{1}{P\dot{L}} + \frac{1}{P\dot{l}} + \frac{1}{P\dot{m}} + \&c.$$

nt quoties puncta K, L, M, &c.
omnia ad eaſdem partes puncti
rectarum AP, BP, CP, &c. ad
iſdem ſigni. Si vero, cæteris
quævis M et *m* cadant ad contra
m creſcentibus reliquis ordinatæ
o minuuntur ordinatæ CP
s pro ſubditititiis ſeu negativis habe

hoc caſu $\frac{1}{PK} + \frac{1}{PL} - \frac{1}{PM} + \&c.$

, &c. & generaliter in ſummis

ni iiſdem vel contrariis ſignis ab
ſegmenta cadunt ad eaſdem ve
puncti dati P.

PE occurrat curvæ in tot punctis

ipſa eſt dimenſionum, ſumma $\frac{1}{PK}$

c. quam conſtantem ſeu invaria

is, æqualis erit ſummæ ſeu aggre

$\frac{1}{l}$ + &c. i. e. ſummæ reciproca

PE poſitione datæ puncta data

tis; in qua, ſi ſegmentum quodvis

puncti P, hujus reciproca ſubtan

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Fig. 8.

Fig. 9.

Fig. 10.

$$+ \frac{E\dot{P}}{PM} + \&c. = \frac{E\dot{P}}{P\ell} + \frac{E\dot{P}}{Pl} + \frac{E\dot{P}}{Pm} + \&c. \text{ et } \frac{1}{PK}$$

$$+ \frac{1}{PL} + \frac{1}{PM} + \&c. = \frac{1}{P\ell} + \frac{1}{Pl} + \frac{1}{Pm} + \&c.$$

Hæc ita ſe habent quoties puncta K, L, M, &c. et *k*, *l*, *m*, &c. ſunt omnia ad eaſdem partes puncti P, adeoque fluxiones rectarum AP, BP, CP, &c. *a*P, *b*P, *c*P, &c. omnes ejuſdem ſigni. Si vero, cæteris manentibus, puncta quævis M et *m* cadant ad contrarias partes puncti P, tum creſcentibus reliquis ordinatis AP, BP, &c. neceſſario minuuntur ordinatæ CP & *c*P, earumque fluxiones pro ſubditiiis ſeu negativis habendæ ſunt; adeoque in hoc caſu $\frac{1}{PK} + \frac{1}{PL} - \frac{1}{PM}$, &c. = $\frac{1}{P\ell} + \frac{1}{Pl} - \frac{1}{Pm}$, &c. & generaliter in ſummis hiſce colligendis, termini iiſdem vel contrariis ſignis afficiendi ſunt, prout ſegmenta cadunt ad eaſdem vel ad contrarias partes puncti dati P.

Fig. 7.

§ 10. Si recta PE occurrat curvæ in tot punctis D, E, I, &c. quot ipſa eſt dimenſionum, ſumma $\frac{1}{PK} + \frac{1}{PL} + \frac{1}{PM} + \&c.$ quam conſtantem ſeu invariatam manere oſtendimus, æqualis erit ſummæ ſeu aggregato $\frac{1}{PD} + \frac{1}{PE} + \frac{1}{PI} + \&c.$ i. e. ſummæ reciprocarum ſegmentis rectæ PE poſitione datæ puncto dato P & curva terminatis; in qua, ſi ſegmentum quodvis ſit ad alteras partes puncti P, hujus reciproca ſubducenda eſt.

§ 11.

§ 11. Si figura ſit ſectio conica, cui recta PE nulli occurrat, inveniatur punctum *b* ut in Art. 7. jungatur P*b*, huic ducatur ad rectos angulos *bd* rectam PE ſecans in *d*, eritque $\frac{1}{PK} + \frac{1}{PL} = \frac{2}{Pd}$. Eſt enim PA × PB ad $bP^2$ in ratione conſtanti, adeoque (per Art. 8.) $\frac{A\dot{P}}{AP} + \frac{B\dot{P}}{BP} = \frac{2b\dot{P}}{bP}$, unde (quoniam $A\dot{P}$ eſt ad $E\dot{P}$ ut AP ad PK, $B\dot{P}$ ad $E\dot{P}$ ut BP ad PL, & $b\dot{P}$ ad $E\dot{P}$ ut *b*P ad *d*P) $\frac{1}{PK} + \frac{1}{PL} = \frac{2}{Pd}$. Fig. 8.

§ 12. Similiter ſi recta EP occurrat lineæ tertii ordinis in unico puncto D, inveniatur punctum *b* ut in Art. 6. recta *bd* perpendicularis in junctam *b*P occurrat rectæ EP in *d*, & quoniam AP × BP × CP eſt ad DP × $bP^3$ in ratione conſtanti (*ibid.*) erit $\frac{1}{PK} + \frac{1}{PL} + \frac{1}{PM} = \frac{1}{PD} + \frac{2}{Pd}$. Si autem P*b* perpendicularis ſit in rectam EP, evaneſcet $\frac{2}{Pd}$. Fig. 9.

§ 13. Aſymptoti linearum geometricarum ex data plaga crurum infinitorum per hanc propoſitionem determinantur; eæ enim conſiderari poſſunt tanquam tangentes cruris in infinitum producti. Recta PA aſymptoto parallela curvæ occurrat in punctis A, B, &c. recta autem PE curvam ſecet in D, E, I, &c. ſumatur in hac recta PM ita ut $\frac{1}{PM}$ ſit æqualis exceſſui quo ſumma $\frac{1}{PD} + \frac{1}{PE} + \frac{1}{PI}$ + &c. ſuperat ſummam $\frac{1}{PK} + \frac{1}{PL}$ + &c. & aſymptotos tranſibit per M, ſi vero Fig. 10.

æquales

æquales ſint hæ ſummæ, crus curvæ parabolicum erit, aſymptoto abeunte in infinitum.

§ 14. Ad *curvaturam* linearum geometricarum unico theoremate generali definiendam, ſit CDR circulus cui occurrant recta PR in D & R, & recta PC in C & N; ſecet tangens CM rectam PD in M, atque manente recta DR, ſupponamus rectam PCN deferri motu ſibi ſemper parallelo donec coincidant puncta P, D, C, & quæratur ultimus valor differentiæ $\frac{1}{PM} - \frac{1}{PD}$. In recta PN ſumatur punctum quodvis $q$, occurrat $qv$ parallela tangenti CM rectæ DR in $v$; ducatur DQ parallela ipſi PN, & QV (parallela rectæ circulum contingenti in D) ſecet DR in V. Erit itaque $\frac{1}{PM} - \frac{1}{PD} = \frac{DM}{PM \times PD}$ (quoniam $DM \times MR = CM^2$) $= \frac{CM^2 \times PM}{PM^2 \times PD \times MR}$ $= \frac{qv^2 \times PM}{Pv^2 \times MR \times PM + Pv^2 \times MR \times MD}$ (cum MR × MD, ſeu $CM^2$, ſit ad $PM^2$ ut $qv^2$ ad $Pv^2$) $= \frac{qv^2 \times PM}{Pv^2 \times MR \times PM + qv^2 \times PM^2} = \frac{qv^2}{Pv^2 \times MR + qv^2 \times PM}$, cujus ultimus valor, evaneſcente PM & coincidentibus $qu$ & Pv cum QV & DV, eſt $\frac{QV^2}{DV^2 \times DR}$. Atque idem eſt valor ultimus differentiæ $\frac{1}{PM} - \frac{1}{PD}$ ſi D & C ſint in arcu lineæ cujuſvis ejuſdem curvaturæ cum circulo CDR.

Fig. 11.

Fig. 12. § 15. Theor. II. *Ex puncto quovis* D *lineæ geometricæ ducantur duæ quævis rectæ* DE, DA, *quarum utraque eam ſecet in tot punctis* D, I, E, *&c. &* D, A, B, *&c. quot ipſa eſt dimenſionum; abſcindant tangentes* AK,

: hæ ſummæ, crus curvæ parabolicæ e
ɔeunte in infinitum.

urvaturam linearum geometricarum uno
nerali definiendam, ſit CDR circulus c
a PR in D & R, & rectæ PC in C & S,
CM rectam PD in M, atque nascen
ponamus rectam PCN deferri motu ſu
o donec coincidant puncta P, D, C, i
ius valor differentiæ $\frac{1}{PM}-\frac{1}{PD}$ hæc
nctum quodvis $q$, occurrat $qv$ paralle
rectæ DR in $v$; ducatur DQ paralle
(parallelæ rectæ circulum contingent
R in V. Erit itaque $\frac{1}{PM}-\frac{1}{PD}=$
um $DM\times MR=CM^2$)$=\frac{CM^2\times PM}{PM^2\times PD\times MI}$

$\frac{qv^2\times PM}{\times PM+Pv^2\times MK\times MD}$ (cum MR
$CM^2$, fit ad $PM^2$ ut $qv^2$ ad $Pv$) $=$
$\frac{PM}{+qv^2\times PM^2}=\frac{pv^2}{Pv^2\times MK+pv^2\times PM}$
lor, evaneſcente PM & coincidentibus
& DV, eſt $\frac{QV^2}{DV^2\times DR}$. Atque idem
differentiæ $\frac{1}{PM}-\frac{1}{PD}$ ſi D & C ſint
uſvis ejuſdem curvaturæ cum circulo

I. *Ex puncto quovis D linea quæ-*
*e quævis rectæ* DE, DA, *quarum*
*n tot punctis* D, I, E, *&c. &* D, A,
*rſt dimenſionum; obſcindant tangentes* AK,



AK, BL,
Occurrat
DA & D
1; fuma
excessui s
+ 1/DL
scriptus
sive ejus
punctum
Oste
summa
+ 1/P
rem u
punct
ejusd
recta
1/DE
proc
ma
nati
pun
ties
sum
hib
rum

AK, BL, *&c. a recta* DE *segmenta* DK, DL, *&c. Occurrat recta quævis,* QV *tangenti* DT *parallela ipsis* DA *&* DE *in* Q *&* V, *sitque* $QV^2$ *ad* $DV^2$ *ut m ad* 1; *sumatur in* DE *recta* DR *ita ut* $\frac{m}{DR}$ *æqualis sit excessui summæ* $\frac{1}{DE} + \frac{1}{DI} +$ *&c. supra summam* $\frac{1}{DK} + \frac{1}{DL} +$ *&c. & circulus supra chordam* DR *descriptus rectam* DT *contingens erit circulus osculatorius, seu ejusdem curvaturæ cum linea geometrica proposita, ad punctum* D.

Ostendimus enim in Art. 10. (Fig. 6.) generaliter summam $\frac{1}{PK} + \frac{1}{PL} + \frac{1}{PM} +$ &c. $= \frac{1}{PD} + \frac{1}{PE} + \frac{1}{PI} +$ &c. & in Art. præcedente invenimus valorem ultimum differentiæ $\frac{1}{PM} - \frac{1}{PD}$, coincidentibus punctis P, D & C, esse $\frac{QV^2}{DV^2 \times DR} = \frac{m}{DR}$ si circulus ejusdem curvaturæ cum linea geometrica ad punctum D rectæ DE occurrat in R. Unde sequitur fore $\frac{m}{DR} = \frac{1}{DE} + \frac{1}{DI} +$ &c. $- \frac{1}{DK} - \frac{1}{DL} -$ &c. sive reciprocam ipsi $\frac{1}{m} \times$ DR esse æqualem excessui quo summa reciprocarum segmentis puncto D & curva terminatis superat summam reciprocarum segmentis eodem puncto & tangentibus AK, BL, &c. terminatis. Quoties autem excessus hic evadit negativus, chorda DR sumenda est ad alteras partes puncti D, semperque adhibenda est regula superius descripta pro signis terminorum dignoscendis. Si recta DA bisecet angulum EDT recta

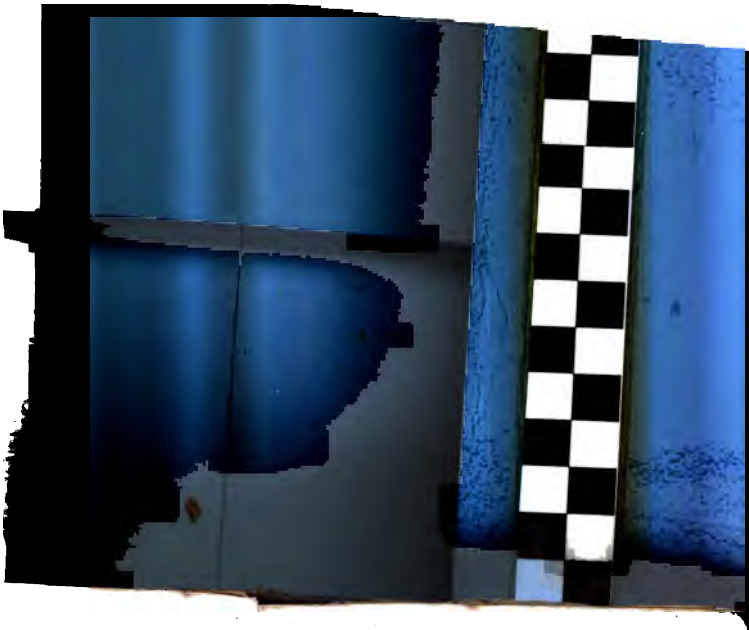
recta DE & tangente DT contentum, theorema fit paulo simplicius. Hoc enim in casu $QV = DV, m = 1$; & $\frac{1}{DR}$ æqualis excessui quo $\frac{1}{DE} + \frac{1}{DI}$ + &c. superat $\frac{1}{DK} + \frac{1}{DL}$ + &c.

§ 16. Ex eodem principio consequitur theorema generale quo determinatur variatio curvaturæ vel mensura anguli contactus curva & circulo osculatorio contenti, in linea quavis geometrica; præmittenda tamen est explicatio brevis variationis curvaturæ, cum hæc non satis dilucide apud auctores descripta sit. Linea quævis curva a tangente flectitur per curvaturam suam, cujus eadem est mensura ac anguli contactus curva & tangente contenti; & similiter curva a circulo osculatorio inflectitur per variationem curvaturæ suæ, cujus variationis eadem est mensura ac anguli contactus curva & circulo osculatorio comprehensi. Occurrat recta TE tangenti DT per-

Fig. 13.

pendicularis curvæ in E & circulo osculatorio in *r*, & variatio curvaturæ erit ultimo ut E*r* subtensa anguli contactus EDr si detur DT; eumque dato angulo contactus EDr fit E*r* ultimo ut DT², ut ex Art. 369. tractatus de fluxionibus colligitur, generaliter curvaturæ variatio erit ultimo ut $\frac{Er}{DT^2}$. Utimur circulo ad curvaturam aliarum figurarum definiendam; verum ad variationem curvaturæ mensurandam, quæ in circulo nulla est, adhibenda est parabola vel sectio aliqua conica. Quemadmodum autem ex circulis numero indefinitis qui curvam datam in puncto dato contingere possunt, unicus dicitur osculatorius qui curvam adeo intime tangit ut nullus alius circulis inter hunc & curvam duci possit; similiter omnium parabolarum quæ eandem habent curvaturam cum linea proposita ad punctum datum

(sunt





cta DE & tangente DT contentum, thom
ulo ſimplicius. Hoc enim in caſu QV = DI
$\frac{1}{DK}$ æqualis exceſſui quo $\frac{1}{DE} + \frac{1}{DI} + \&c.$
$\frac{1}{DK} + \frac{1}{DL} + \&c.$

§ 16. Ex eodem *principio* conſequitur theor
ale quo *determinatur* variatio curvaturæ re
uli *contactus* curvæ & circulo oſculatorio in
nea *quavis geometrica*; præmittenda tamen
itio brevis variationis curvaturæ, cum hac m
ide apud auctores deſcripta ſit. Linea quam
ente flectitur per curvaturam ſuam, cujus
nſura ac angoli contactus curva & tangen
& ſimiliter curva a circulo oſculatorio abi
ationem curvaturæ ſuæ, cujus variationis m
ura ac anguli contactus curva & circulo
prehenſi. Occurrat recta TE tangenti DT
aris curvæ in E & circulo oſculatorio in
curvaturæ erit ultimo ut Er ſubtenſa an
s ED, ſi denique DT; eumque dato angulo
Dr ſit Er ultimo ut DT², ut ex Art. 3
de fluxionibus colligitur, generaliter curva
it ultimo ut $\frac{Er}{DT^2}$. Utimur circulo ad
iarum figurarum definiendam; verum ub
urvaturæ menſurandam, quæ in circulo ni
nda eſt parabola vel ſectio aliqua con
dium autem ex circulis numero infinit
datam in puncto dato contingen poſſi
ur oſculatorius qui curvam adeo intime
s alius circulis inter hunc & curvam in
iter omnium parabolarum quæ eandem li
ram cum linea propoſita ad punctum dat
ſint



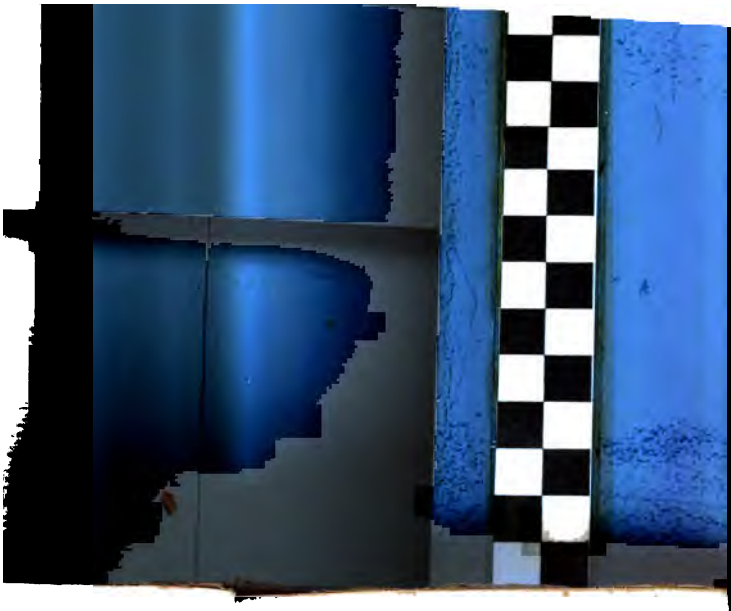
(ſunt autem hæ quoque numero infinitæ) ea eandem ſimul habet curvaturæ variationem, quæ, non ſolum arcum curvæ tangit & oſculat, ſed adeo premit ut nullus alius arcus parabolicis duci poſſit inter eas, reliquis omnibus arcubus parabolicis tranſeuntibus vel extra vel intra utraſque. Qua vero ratione hæc parabola determinari poſſit, ex iis quæ alibi fuſius explicavimus facile intelligitur.

Sit DE arcus curvæ, DT tangens, TEK recta tangenti perpendicularis, ſitque rectangulum ET × TK ſemper æquale quadrato tangentis DT, & curva SKF locus puncti K, qui rectæ DS curvæ normali occurrat in S, quemque tangat in S recta SV tangentem TD ſecans in V. Recta DS erit diameter circuli oſculatorii, & biſecta DS in ſ, erit ſ centrum curvaturæ; junctâ autem Vſ, ſi angulus SDN conſtituatur æqualis angulo ſVD ex altera parte rectæ DS, & recta DN circulo oſculatorio occurrat in N; tum parabola diametro & parametro DN deſcripta, quæque rectam DT contingit in D, ipſa erit cujus contactus cum linea propoſita in D intimus erit atque maxime perfectus ſeu proximus. Omnes autem parabolæ aliâ quavis chorda circuli oſculatorii tanquam diametro & parametro deſcriptæ, & rectam DT contingentes in D, eandem habent curvaturam cum linea propoſita in puncto D. Qualitas curvaturæ a *Newtono* in opere poſthumo nuper edito explicata eſt potius variatio radii curvaturæ; eſt enim ut fluxio radii curvaturæ applicata ad fluxionem curvæ, vel (ſi R denotet radium circuli oſculatorii & S arcum curvæ ut $\frac{\dot{R}}{S}$. Ipſa autem curvatura eſt inverſe ut radius R, & variatio curvaturæ ut $\frac{-\dot{R}}{RRS}$, quæ eſt menſura anguli

guli contactus curvâ & circulo oſculatorio contenti. Harum autem una ex alterâ datâ facile derivatur. Variatio radii curvaturæ in curvâ quavis DE eſt ut tangens anguli DVS vel DV*ſ*, & in parabolâ quavis eſt ſemper ut tangens anguli contenti diametro per punctum contactus tranſeunte & rectâ ad curvam perpendiculari. Hæc ex theoremate ſequenti generali deduci poſſunt:

Fig. 14. § 17. Theor. III. *Sit* D *punctum in linea quavis geometrica datum, occurrat* DS *diameter circuli oſculatorii per* D *ducta curvæ in tot punctis* D, A, B, *&c. quot ipſa eſt dimenſionum; ducatur* DT *curvam contingens in* D, *quæ curvam ſecet in punctis* I, *&c. binaris* K, L, *&c. eritque variatio curvaturæ, ſive menſura anguli contactus curvæ & circulo oſculatorio comprehenſi, directe ut exceſſus quo ſumma reciprocarum ſegmentis tangentis* DT *puncto contactus* D *& tangentibus* AK, BL, *&c. terminatis ſuperat ſummam reciprocarum ſegmentis eodem puncto & curva terminatis, & inverſe ut radius curvaturæ, i. e. ut* $\frac{1}{DS} \times \overline{\frac{1}{DK} + \frac{1}{DL} + \&c. - \frac{1}{DI} - \&c.}$.

Ducatur enim recta D*k* curvam ſecans in *e*, *i*, &c, circulum oſculatorium in R; ſitque angulus *k*DT quam minimus; hujus ſupplementum ad duos rectos biſecetur rectâ *Dab*, quæ lineæ geometricæ propoſitæ occurrat in punctis D, *a*, *b*, &c. & ductæ tangentes *ak*, *bl*, &c. ſecent rectam D*k* in punctis *k*, *l*, &c. eritque per propoſitionem præcedentem $\frac{1}{DR} = \frac{1}{De} + \frac{1}{Di} - \frac{1}{Dk} - \frac{1}{Dl}$, &c. Unde $\frac{1}{DR} - \frac{1}{De}$ (ſive $\frac{Re}{DR \times De}$) $= \frac{1}{De}$





*ili contactus curvâ & circulo* osculatorio
*rum autem unâ ex aliarum datâ facile deriv*
*tio radii curvaturæ in curvâ quavis* DE
*us anguli DVS vel DV∫, & in paraboli*
*per ut tangens anguli contenti diamet*
*n contactus transeunte & rectâ ad curvam*
*i. Hæc ex theoremate sequenti gen*
*ic.*

*7. Theor. III. Sit* D *punctum in in*
*ica datum, occurrat* DS *diametro in*
*r* D *ducta curvæ in tot punctis* D, A,
*a est dimensionum; ducatur* DT *curv*
D, *quæ curvam secet in punctis* I, &
*its, & occurrat tangentibus* AK, BL,
*&c. eritque variatio curvaturæ, five* m
*actus curvæ & circulo osculatorio* m
*excessus quo summa reciprocarum* se
T *puncto contactus* D *& tangentibus* AK
*minatis superat summam reciprocarum* se
*nctio & curva terminatis, & inter* s
*e*, i. e. *ut* $\frac{1}{DS} \times \overline{\frac{1}{DK} + \frac{1}{DL} + \&c. - \frac{1}{DI}}$

*ur enim recta* D*k* *curvæ* *occurrat in* A,
*osculatorium in* R; *sitque angulus* *DT*
; *hujus supplementum ad duos rectos* *hic*
, *quæ lineæ geometricæ proponi* *ecs*
D, *a*, *b*, &c. & *ductæ tangentes* *ad*, *AK*
*lam* D*k* *in punctis* *k*, *l*, &c. *eritque*

*præcedentem* $\frac{1}{DR} = \frac{1}{De} + \frac{1}{Di} -$

Unde $\frac{1}{DR} - \frac{1}{De}\left(\text{five } \frac{Re}{DR \times De}\right) =$

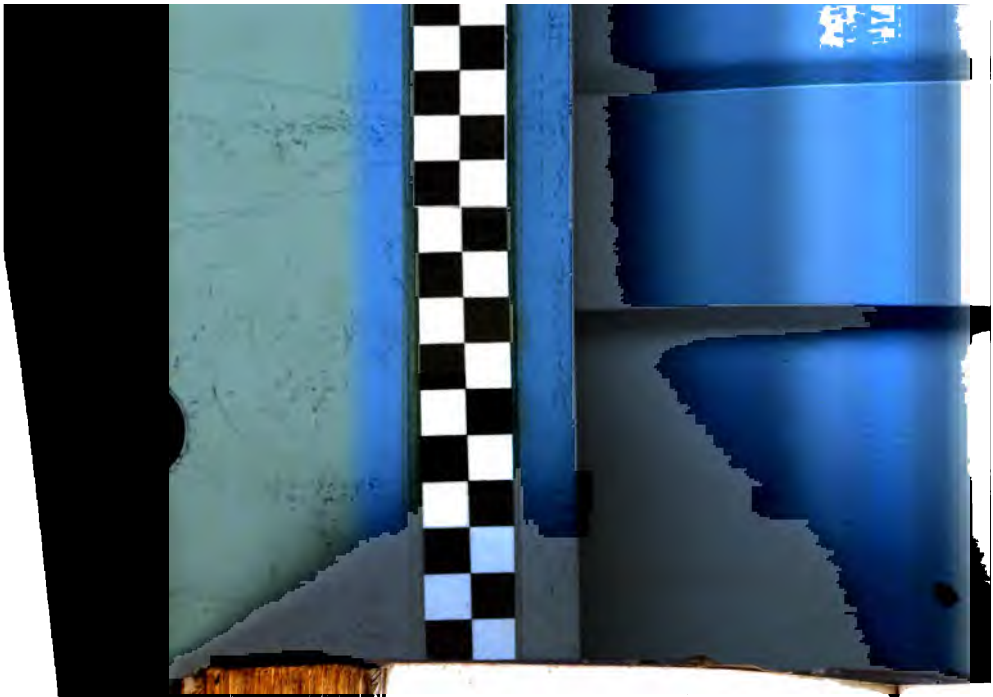


$- \frac{1}{Dk} - \frac{1}{DI}$ — &c. Proinde coincidentibus rectis D*k* & DK, seu evanescente angulo *k*DK, erit ultimo $\frac{Re}{DR \times De}$ æqualis $\frac{1}{DI} - \frac{1}{DK} - \frac{1}{DL}$ — &c. Sit *er*T perpendicularis tangenti in T, atque occurrat circulo osculatorio in *r*; cumque fit *re* ultimo ad R*e* ut *e*T ad D*e*, erit ultimo $\frac{Re}{DR \times De} = \frac{re}{DR \times eT} = \frac{re \times DS}{DR \times DT^2}$, five $\frac{re \times DS}{DT^2}$. Mensura autem anguli contactus *r*D*e* curva & circulo osculatorio contenti, five variatio curvaturæ, est ut $\frac{re}{DT^2}$ adeoque ut $\frac{1}{DS} \times \overline{\frac{1}{DI} - \frac{1}{DK} - \frac{1}{DL}}$, &c.

§ 18. Variatio autem radii curvaturæ, five hujus qualitas a *Newtono* descripta, ex priori facillime colligitur. Junctis enim SI, SK, SL, &c. erit hæc variatio radii osculatorii ut excessus quo summa tangentium angulorum DKS, DLS, &c. superat summam tangentium angulorum DIS, &c. Crescit autem curvatura a puncto D versus *e*, & minuitur radius osculatorius, quoties arcus D*e* tangit circulum osculatorium DR interne, vel cum $\frac{1}{DK} + \frac{1}{DL}$ + &c. superat $\frac{1}{DI}$ + &c: at contrà minuitur curvatura a D versus *e*, & augetur radius circuli osculatorii, quoties arcus curvæ D*e* tangit arcum circularem externe vel tranfit intra circulum & tangentem adeoque cum DR fit ultimo minor quam D*e* vel cum $\frac{1}{DI}$ + &c. superat $\frac{1}{DK} + \frac{1}{DL}$ + &c.

§ 19. Sumatur igitur in tangente DT recta DV ita ut $\frac{1}{DV} = \frac{1}{DK} + \frac{1}{DL}$ + &c. $- \frac{1}{DI}$ — &c. jungatur

 *V*,

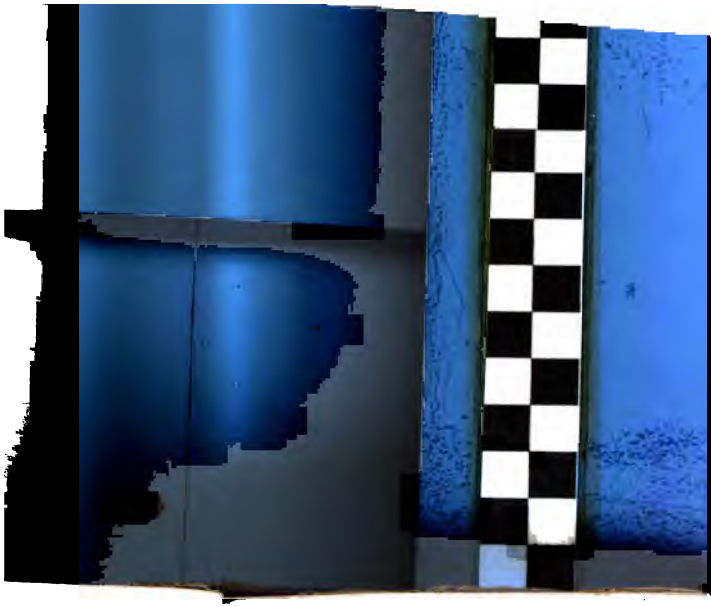




ſV, conſtituatur angulus SDN æqualis DVſ, atque occurrat recta DN circulo oſculatorio in N; & parabola diametro DN deſcripta, cujus parameter eſt DN, quæque rectam DT contingit in D, eandem habebit variationem curvaturæ cum linea geometrica propoſita in puncto D. Ex iiſdem principiis alia quoque theoremata deducuntur, quibus variatio curvaturæ in lineis geometricis generaliter definitur.

§ 20. Ut hæc theoremata ad formam magis geometricam reducantur, lemmata quædam ſunt præmittenda, quibus doctrina de diviſione rectarum harmonicâ amplior & generalior reddatur. In recta quavis DI, ſumptis æqualibus ſegmentis DF & FG, ducantur a puncto quovis V quod non eſt in recta DI tres rectæ VD, VF, VG, & quarta VL ipſi DI parallela, atque hæ quatuor rectæ, a Cl. D. *De la Hire*, Harmonicales dicuntur. Recta vero quævis, quæ quatuor harmonicalibus occurrit ab iiſdem harmonice ſecatur. Occurrat recta DC harmonicalibus VD, VF, VG, & VL in punctis D, A, B, C; erit que DA ad DC ut AB ad BC. Ducatur enim per punctum A recta MAN ipſi DI parallela, quæ occurrat rectis VD & VG in M & N; & ob æquales DF & FG, æquales erunt MA & AN. Eſt autem DA ad DC ut AM (ſive AN) ad VC, adeoque ut AB ad BC. Manifeſtum eſt rectam, quæ uni harmonicalium parallela eſt, dividi in æqualia ſegmenta a tribus reliquis. Occurrat recta BH parallela ipſi VF reliquis VG, VC, VD in B, K, & H; eritque VK ad KB ut FG (vel DF) ad VF adeoque ut VK ad KH, & proinde BK = KH. Fig. 15.

§ 21. Hinc ſequitur, ſi recta quævis a quatuor rectis ab eodem puncto ductis ſecetur harmonice, aliam quamvis





conſtituatur angulus SDN æqualis DN
rat recta *DN* circulo oſculatorio in N; ip
ametro *DN* deſcripta, cujus parameter d
: rectam *DT* contingit in D, eandem
nem curvaturæ cum linea geometrica pu
to D. *Ex iiſdem principiis alia quoque*
ducuntur, quibus variatio curvaturæ in
cis generaliter definitur.

t hæc theoremata ad formam magis ge
ucantur, *lemmata* quædam ſunt præmi
ctrina de diviſione rectarum harmonic
neralior reddatur. In recta quavis *A*
bus ſegmentis DF & FG, ducantur pu
juod non eſt in recta DI tres rectæ VA
iarta VL ipſi DI parallela, atque ter
a Cl. D. *De la Hire*, Harmonicales ſu
a vero quævis, quæ quatuor harmon
it ab iiſdem harmonice ſecatur. Occ
harmonicalibus VD, VF, VG, & VA
A, B, C; eritque DA ad DC ut AB ad
ium per punctum A recta MAN ipſi DB
e occurrat rectis VD & VG in M & N
DF & FG, æquales erunt MA & A
DA ad DC ut AM (ſive AN) ad C
AB ad BC. Manifeſtum eſt rectam, qu
talium parallela eſt, dividi in æquales
es reliquis. Occurrat recta BH prædi
quis VG, VC, VD in B, K, & H; er
CB ut FG (vel DF) ad VF adeoque
& proinde BK = KH.

ſequitur, ſi recta quævis a quatuor ad
cto ductis ſecetur harmonice, aliam quæ
vis rectam quæ iiſ quatuor rectis occurrit harmonice ſecari ab iiſdem; eam vero quæ parallela eſt uni quatuor rectarum in ſegmenta æqualia dividi a tribus reliquis. Sit DA ad DC ut AB ad BC, jungantur VA, VB, VC, & VD; occurrant rectæ MAN, DFG ipſi VC parallelæ rectis VD, VA, & VB in M, A, N & D, F, G; eritque MA ad VC ut DA ad DC, vel AB ad BC, adeoque ut AN ad VC; MA = AN, & DF = FG; &, per præcedentem, recta quævis quæ ipſis VD, VA, VB, VC occurrit harmonice ſecabitur ab iiſdem.

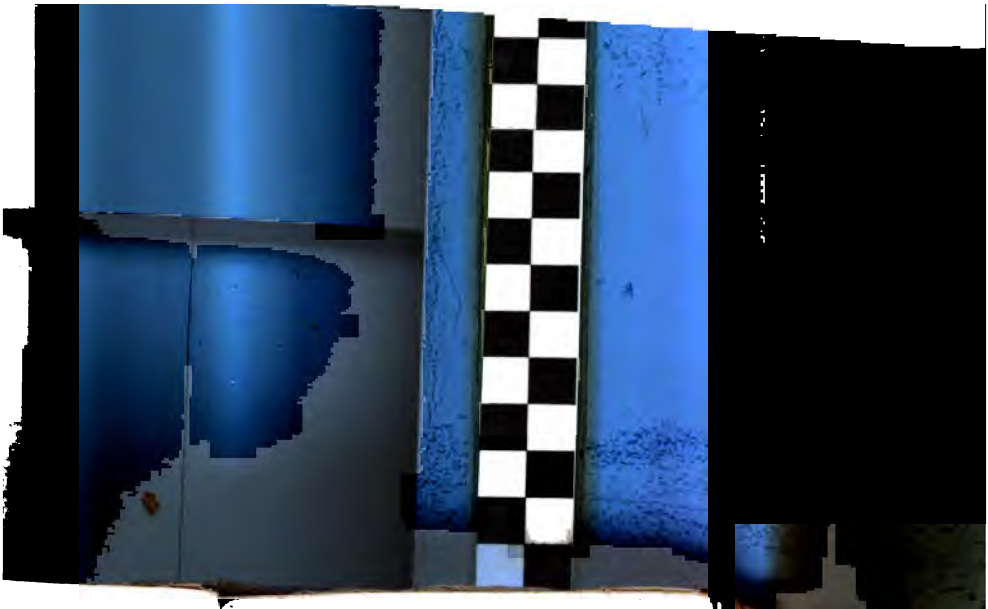
§ 22. Ex puncto D ducantur duæ rectæ DAC, D*ac* rectas VA & VC ſecantes in punctis A, C atque *a*, *c*; junctæ A*c* & *a*C ſibi mutuo occurrant in Q, & ducta VQ harmonice ſecabit rectam DAC vel aliam quamvis rectam ex puncto D ad eaſdem rectas ductam. Secet enim VQ rectam AC in B, & per punctum Q ducatur recta MQN parallela ipſi DC, quæ occurrat rectis D*a*, VA & VC in punctis M, R, & N; eumque ſit MR ad MQ ut DA ad DC, & MQ ad MN in eadem ratione, erit quoque RQ ad QN ut DA ad DC. Sed RQ eſt ad QN ut AB ad BC. Quare DA eſt ad DC ut AB ad BC. Hæc eſt Prop. 20ma, Lib. I. ſectionum conicarum Cl. *De la Hire*. Fig. 16. n. 1.

§ 23. Sit DA ad DC ut AB ad BC, eritque $\frac{2}{DB}$ æqualis ſummæ vel differentiæ ipſarum $\frac{1}{DA}$ & $\frac{1}{DC}$ prout puncta A & C ſunt ad eaſdem vel contrarias partes puncti D. Sint imprimis puncta A & C ad eaſdem partes puncti D, eumque ſit $DA \times BC = DC \times AB$, i.e. $DA \times \overline{DC - DB} = DC \times \overline{DB - DA}$; vel $DA \times \overline{DB - DC} = DC \times \overline{DA - DB}$ erit $2DA \times DC = DA \times DB + DC$

DC × DB, adeoque $\frac{2}{DB} = \frac{1}{DA} + \frac{1}{DC}$. Sint nunc

n. 2 & 3. puncta A & C ad contrarias partes puncti D, eritque vel $DA \times \overline{DB - DC} = DC \times \overline{DB + DA}$, vel $DA \times \overline{DB + DC} = DC \times \overline{DB - DA}$, adeoque $\frac{2}{DB} = \frac{1}{DC} - \frac{1}{DA}$ cum puncta B & C sint ad easdem partes puncti D, vel $\frac{2}{DB} = \frac{1}{DA} - \frac{1}{DC}$ quoties puncta A & B sunt ad easdem partes puncti D. Si igitur, datis puncto D & rectis VF & VC positione, ducatur ex puncto D recta quævis illis occurrens in punctis A & C, & in eadem recta sumatur semper DB ita ut $\frac{2}{DB} = \mp \frac{1}{DA} \mp \frac{1}{DC}$, ubi supponitur terminos $\frac{1}{DA}$ & $\frac{1}{DC}$ iisdem vel contrariis signis afficiendos esse prout puncta A & C sunt ad easdem vel contrarias partes puncti D, erit locus puncti B ipsa harmonicalis VG quæ rectam DFG rectæ VC parallelam secat in G ita FG = DF; quæque transit per punctum Q ubi (ducta Dac quæ iisdem rectis VF & VC occurrat in *a* et *c*) junctæ Ac et aC se mutuo decussant.

Fig. 17. § 24. Si in recta DA sumatur semper D*b* ita ut $\frac{1}{Db} = \frac{1}{DA} \mp \frac{1}{DC}$, ducatur DF parallela rectæ VC quæ rectæ VF occurrat in F, & DH parallela rectæ VF quæ rectæ VC occurrat in H, & ducta diagonalis HF erit locus puncti *b*; nam ex hypothesi $\frac{1}{Db} = \frac{2}{DB}$, & DB = 2D*b*; adeoque cum VG sit locus puncti B erit punctum *b* ad rectam HF, si puncta A & C sint ad easdem





DB, adeoque $\frac{2}{DB} = \frac{1}{DA} + \frac{1}{DC}$. Sunt
A & C ad contrarias partes puncti D, ut
$\times DB - DC = DC \times DB + DA$, vel
$DC = DC \times \overline{DB - DA}$, adeoque $\frac{2}{DB} =$
um puncta B & C simul ad eadem partes
$\frac{1}{B} = \frac{1}{DA} - \frac{1}{DC}$ quoties puncta A &
partes puncti D. Si igitur, datis pun
F & VC positione, ducatur ex punc
ris illis occurrens in punctis A & C,
a sumatur semper DB ita ut $\frac{2}{DB} =$
ubi supponitur terminos $\frac{1}{DA}$ & $\frac{1}{DC}$ in
is signis efficiendos esse prout puncta
lem vel contrarias partes puncti D, ex
B ipsa harmonicalis VG quæ rectæ DF
arallelam, secat in G ita $FG = DF$; ex
per punctum Q ubi (ducta Du qu
VF & VC occurrat in a et c) junc
tuo decussant.

a recta DA sumatur semper Dh in a
$\frac{1}{DC}$; ducatur DF parallela rectæ V
occurrat in F, & DH parallela rectæ
occurrat in H, & ducta diagonali
ti b; nam ex hypothesi $\frac{1}{Dh} = \frac{2}{DB}$,
deoque cum VG sit locus puncti B ad
rectam HF, si puncta A & C sint
cadem



eadem partes puncti D. Si autem supponatur $\frac{1}{Db} = \frac{1}{DA} + \frac{1}{DC}$, eadem constructio inserviet pro determinando puncto b, si substituatur loco rectæ VC alia vc rectæ VC parallela ad æqualem distantiam a puncto D sed ad contrarias partes.

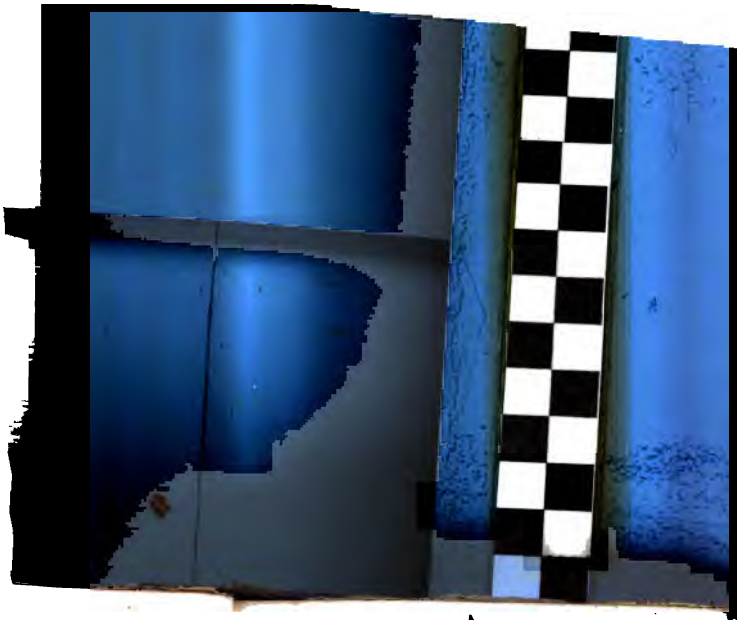
§ 25. Ex puncto dato D ducatur recta quævis DM quæ tribus rectis positione datis occurrat in punctis A, C, E; & sumatur semper DM ita ut $\frac{1}{DM} = \frac{1}{DA} + \frac{1}{DC} + \frac{1}{DE}$ (ubi termini sunt contrariis signis afficiendi quoties rectæ DA, DC vel DE sunt ad contrarias partes puncti D); supponatur $\frac{1}{DA} + \frac{1}{DC} = \frac{1}{DL}$, eritque L ad rectam positione datam per præcedentem; adeoque, cum sit $\frac{1}{DM} = \frac{1}{DL} + \frac{1}{DE}$, erit punctum M ad positione datam, per eandem. Compositio autem problematis facile ex dictis perficitur. Sint VA, VC & vE tres rectæ positione datæ, & compleatur parallelogrammum DFVH, ducendo DF & DH rectis VC & VF respective parallelas, & occurrat recta vE diagonali in v; deinde compleatur parallelogrammum Dfvh ducendo rectas Df & Dh rectis vE & HF parallelas quæ rectis HE & vE occurrant in punctis f & b; & diagonalis bf erit locus puncti M. Occurrat enim recta DA rectis HF & bf in L & M; eritque, ex præcedentibus, $\frac{1}{DM} = \frac{1}{DL} + \frac{1}{DE} = \frac{1}{DA} + \frac{1}{DC} + \frac{1}{DE}$. Alia constructio ex Art. 22. deducitur.

§ 26. Recta quævis ex puncto dato D ducta occurrat rectis positione datis in punctis A, B, C, E, &c. et in hac recta sumatur semper $\frac{1}{DM} = \frac{1}{DA} \mp \frac{1}{DB} \mp \frac{1}{DC} \mp \frac{1}{DE}$, &c. eritque locus puncti M semper ad rectam positione datam. Demonstratur ad modum præcedentis.

Fig. 18. § 27. Theor. IV. *Circa datum punctum* P *revolvatur recta* PD *quæ occurrat lineæ geometricæ cujuscunque ordinis in tot punctis* D, E, I, &c. *quot ipsa est dimensionum, & ſi in eadem recta sumatur semper* PM *ita ut* $\frac{1}{PM} = \frac{1}{PD} \mp \frac{1}{PE} \mp \frac{1}{PI} \mp$ &c. *(ubi signa terminorum regulam ſæpius descriptam observare ſupponimus) erit locus puncti* M *linea recta.*

Ducatur enim ex polo P recta quævis positione data PA, quæ curvæ occurrat in tot punctis A, B, C, &c. quot ipsa est dimensionum. Ducantur rectæ AK, BL, CN curvam in his punctis contingentes, quæ occurrant rectæ PD in totidem punctis K, L, N, &c. et per Art. 10. $\frac{1}{PD} \mp \frac{1}{PE} \mp \frac{1}{PI} \mp$ &c. $= \frac{1}{PK} \mp \frac{1}{PL} \mp \frac{1}{PN} \mp$ &c. Unde $\frac{1}{PM}$ æqualis est huic summæ, cumque positione detur recta PA, & maneant rectæ AK, BL, CN, &c. dum recta PD circa polum P revolvitur, erit punctum M ad lineam rectam, per articulum præcedentem; quæ per superius ostensa ex datis tangentibus AK, BL, &c. determinari potest.

§ 28. Sicuti recta P*m* medium est harmonicum inter duas rectas PD & PE, cum $\frac{2}{Pm} = \frac{1}{PD} + \frac{1}{PE}$; ſimiliter





. Recta quævis ex puncto dato D ducta tor
ositione datis in punctis A, B, C, E, &c.
a sumatur semper $\frac{n}{DM} = \frac{1}{DA} \mp \frac{1}{DB}$
&c. erit que locus punctii M semper alia
datam. Demonstratur ad modum pr

Theor. IV. *Circa datum punctum P mu*
*quæ occurrat lineæ geometricæ cujusc*
*t punctis D, E, I, &c. quot ipsa si in*
*si in eadem recta sumatur semper Pm*
$\frac{n}{Pm} = \frac{1}{PD} \mp \frac{1}{PE} \mp \frac{1}{PI} \mp$ &c. *Ubi signa su*
*um saepius describtam observare suppo*
*recti M linea recta.*

enim ex polo P recta quævis potest
urvæ occurrat in tot punctis A, B, C, e
ft dimensionum. Ducantur rectæ AE, E
m in his punctis contingentes, quæ occurra
in totidem punctis K, L, N, &c. e
$\frac{1}{PD} \mp \frac{1}{PE} \mp \frac{1}{PI} \mp$ &c. $= \frac{1}{PA} \mp \frac{1}{PB}$

Unde $\frac{1}{PM}$ æqualis est huic summæ, cu
e detur recta PA, & maneant rectæ AE,
&c. duæ rectæ PD circa polum P rotab
ctum M ad lineam rectam, per articulos
; quæ per superius ostensa ex datis tu
, BL, &c. determinari potest.

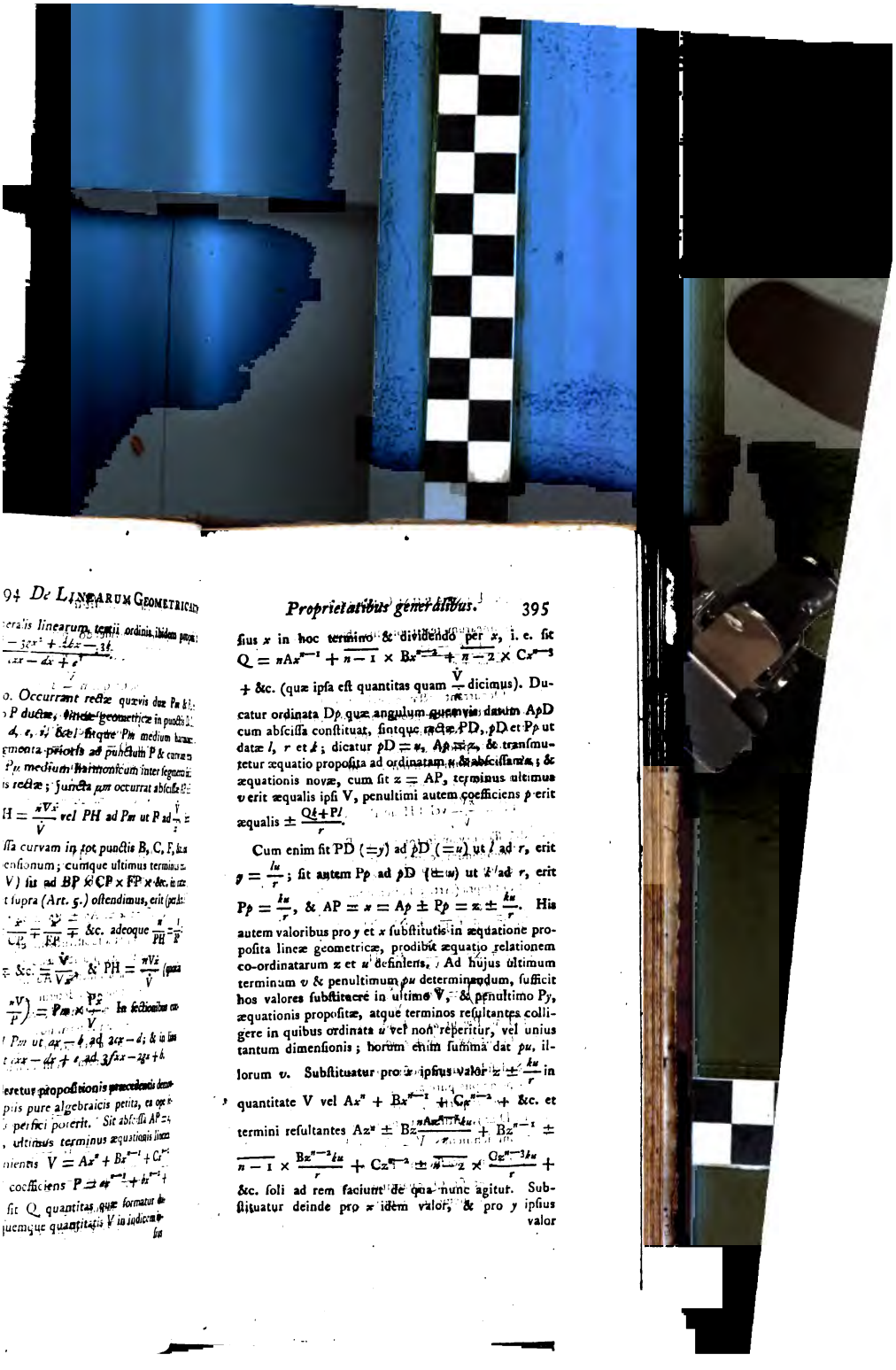
it, recta Pm medium est harmonicum inte
PD & PE, cum $\frac{2}{Pm} = \frac{1}{PD} + \frac{1}{PE}$; si-
militer Pm dicatur *medium* harmonicum inter rectas quaslibet PD, PE, PI, &c. quarum numerus est $n$, cum $\frac{n}{Pm} = \frac{1}{PD} \mp \frac{1}{PE} \mp \frac{1}{PI} \mp$ &c. Et si ex puncto dato P recta quævis ducta lineam geometricam secet in tot punctis quot ipsa est dimensionum, in qua sumatur semper Pm medium harmonicum inter segmenta omnia ductæ ad punctum datum P & curvam terminata, erit punctum $m$ ad rectam lineam. Erit enim $\frac{1}{PM} = \frac{n}{Pm}$ adeoque Pm ad PM ut $n$ ad unitatem; cumque punctum M sit ad rectam lineam, per præcedentem, erit $m$ quoque ad rectam lineam. Atque hoc est theorema *Cotesii*, vel eidem affine.

§ 29. Sint $a$, $b$, $c$, $d$, &c. radices æquationis ordinis $n$, V ultimus ejus terminus quem ordinata seu radix $y$ non ingreditur, P coefficiens termini penultimi, M medium harmonicum inter omnes radices, seu $\frac{n}{M} = \frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d} +$ &c. Cum igitur sit V factum ex radicibus omnibus $a$, $b$, $c$, &c. in se mutuo ductis, sitque P summa factorum cum radicibus omnes unà dempta in se mutuo ducuntur, erit $P = \frac{V}{a} + \frac{V}{b} + \frac{V}{c} + \frac{V}{d} +$ &c. $= \frac{nV}{M}$, adeoque $M = \frac{nV}{P}$. Sic, si æquatio fit quadratica, cujus radices duæ sint $a$ et $b$, erit $M = \frac{2ab}{a+b}$ (assumptâ æquatione generali sectionum conicarum Art. 1. propositâ) $= \frac{2axx - 2dx + 2e}{ax - b}$. In æquatione cubicâ cujus tres radices sunt $a$, $b$, $c$, erit $M = \frac{3abc}{ab + ac + bc}$ (si assumatur æquatio generalis

generalis linearum tertii ordinis, ibidem propositi) æ $\frac{3fx^3 - 3gx^2 + 3bx - 3k}{cxx - dx + e}$.

Fig. 19. § 30. Occurrant rectæ quævis duæ $Pm$ & $P\mu$, ex puncto P ductæ, lineæ geometricæ in punctis D, E, I, &c. et $d$, $e$, $i$, &c. sitque $Pm$ medium harmonicum inter segmenta prioris ad punctum P & curvam terminata, & $P\mu$ medium harmonicum inter segmenta similia posterioris rectæ, puncta $\mu m$ occurrat abscissæ AP in H, eritque $PH = \frac{nVx}{\dot{V}}$ vel PH ad $Pm$ ut P ad $\frac{\dot{V}}{x}$. Secet enim abscissa curvam in tot punctis B, C, F, &c. quot ipsa est dimensionum, cumque ultimus terminus æquationis (i. e. V) sit ad $BP \times CP \times FP \times$ &c. in ratione constanti, ut supra (Art. 5.) ostendimus, erit (per Art. 8.) $\frac{\dot{V}}{V} = \frac{\dot{x}}{BP} + \frac{\dot{x}}{CP} + \frac{\dot{x}}{FP} + \frac{\dot{x}}{EP}$ &c. adeoque $\frac{n}{PH} = \frac{1}{BP} + \frac{1}{CP} + \frac{1}{FP}$ &c. $= \frac{\dot{V}}{nVx}$, & $PH = \frac{nVx}{\dot{V}}$ (quoniam recta $PM = \frac{nV}{\dot{V}} \lambda = Pm \times \frac{Px}{V}$. In sectionibus conicis est PH ad $Pm$ ut $ax - b$ ad $2cx - d$; & in lineis tertii ordinis ut $cxx - dx + e$ ad $3fxx - 2gx + b$.

§ 31. Si desideretur propositionis precedentis demonstratio ex principiis pure algebraicis petita, ea ope sequentis *Lemmatis* perfici poterit. Sit abscissa $AP = x$, ordinata $PD = y$, ultimus terminus æquationis lineam geometricam definiens $V = Ax^n + Bx^{n-1} + Cx^{n-2}$ + &c. penultimi coefficiens $P = ax^{n-1} + bx^{n-2} + cx^{n-3}$ + &c. et sit Q quantitas quæ formatur ducendo terminum quemque quantitatis V in indicem ipsius





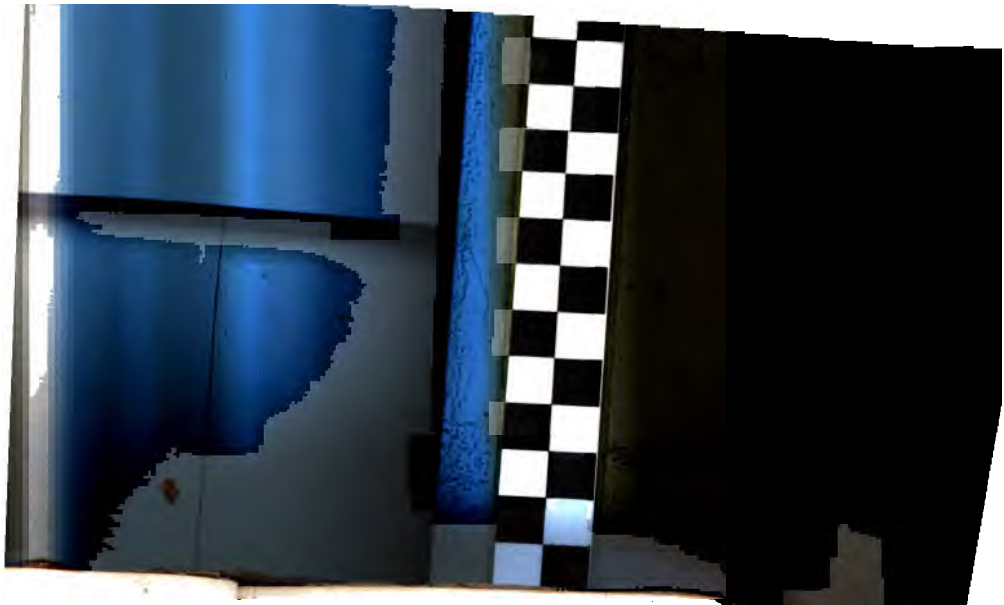


fius $x$ in hoc termino & dividendo per $x$, i. e. fit $Q = nAx^{n-1} + \overline{n-1} \times Bx^{n-2} + \overline{n-2} \times Cx^{n-3}$ + &c. (quæ ipsa eſt quantitas quam $\frac{\dot{V}}{\dot{x}}$ dicimus). Ducatur ordinata Dp quæ angulum quemvis datum ApD cum abſciſſa conſtituat, ſintque rectæ PD, pD et Pp ut datæ $l$, $r$ et $k$; dicatur $pD = u$, $Ap = z$, & tranſmutetur æquatio propoſita ad ordinatam $u$ & abſciſſam $z$; & æquationis novæ, cum ſit $z = AP$, terminus ultimus $v$ erit æqualis ipſi V, penultimi autem coefficiens $p$ erit æqualis $\pm \frac{Qk+Pl}{r}$.

Cum enim ſit $PD (=y)$ ad $pD (=u)$ ut $l$ ad $r$, erit $y = \frac{lu}{r}$; ſit autem $Pp$ ad $pD$ $(=u)$ ut $k$ ad $r$, erit $Pp = \frac{ku}{r}$, & $AP = x = Ap \pm Pp = z \pm \frac{ku}{r}$. His autem valoribus pro $y$ et $x$ ſubſtitutis in æquatione propoſita lineæ geometricæ, prodibit æquatio relationem co-ordinatarum $z$ et $u$ definiens. Ad hujus ultimum terminum $v$ & penultimum $pu$ determinandum, ſufficit hos valores ſubſtituere in ultimo V, & penultimo $Py$, æquationis propoſitæ, atque terminos reſultantes colligere in quibus ordinata $u$ vel non reperitur, vel unius tantum dimenſionis; horum enim ſumma dat $pu$, illorum $v$. Subſtituatur pro $x$ ipſius valor $z \pm \frac{ku}{r}$ in quantitate V vel $Ax^n + Bx^{n-1} + Cx^{n-2}$ + &c. et termini reſultantes $Az^n \pm \frac{nAkz^{n-1}u}{r} + Bz^{n-1} \pm \overline{n-1} \times \frac{Bz^{n-2}ku}{r} + Cz^{n-2} \pm \overline{n-2} \times \frac{Cz^{n-3}ku}{r} +$ &c. ſoli ad rem faciunt de qua nunc agitur. Subſtituatur deinde pro $x$ idem valor, & pro $y$ ipſius valor

valor $\frac{lu}{r}$, in quantitate $Py = \frac{ax^{n-1} + bx^{n-2} + cx^{n-3}}{az^{n-1} + bz^{n-2} + cz^{n-3}}$ + &c. × $y$; & termini reſultantes ſoli $\frac{ax^{n-1} + bx^{n-2} + cx^{n-3}}{az^{n-1} + bz^{n-2} + cz^{n-3}}$ + &c. × $\frac{lu}{r}$ ſunt nobis retinendi. Supponatur nunc $z = x$, & ſumma priorum ſit æqualis $V \pm \frac{Qlu}{r}$, & poſteriorum ſumma $= \frac{Plu}{r}$. Unde manifeſtum eſt ultimum terminum æquationis novæ $v = V$, & penultimum $pu = \frac{Pl \pm Qk}{r} \times u$.

§ 32. Sit nunc $Pm$ medium harmonicum inter ſegmenta PD, PE; $P\iota$, &c. et $P\mu$ medium harmonicum inter ſegmenta $Pd$, $Pe$, $P\iota$, &c. ut in Art. 30. juncta $\mu m$ fecet abſciſſam in H; & ſupponamus $P\mu$ ordinatæ $pD$ parallelam eſſe. Ducatur $\mu s$ abſciſſæ parallela, quæ rectæ $Pm$ occurrat in $s$; eritque $Ps$ ad $P\mu$ ut PD ad $pD$ vel ut $l$ ad $r$, et $\mu s$ ad $P\mu$ ut $k$ ad $r$. Cumque ſit $P\mu = \frac{nv}{p}$ (per Articulum præcedentem) $\frac{nVr}{Pl \pm Qk}$, erit $ms = Pm \pm Py = \frac{nV}{P} \pm \frac{nvl}{pr} = \frac{nV}{P} \pm \frac{nVl}{Pl + Qk} = \frac{nVQk}{P \times Pl \pm Qk}$. Eſt autem $ms$ ad $s\mu$ ut $Pm$ ad PH, i. e. $\frac{nVQk}{P \times Pl \pm Qk}$ ad $\frac{nVk}{Pl \pm Qk}$ ut $Pm$ ad PH; adeoque Q ad P ut $Pm$ ad PH, vel PH $= Pm \times \frac{P}{Q}$ vel $\frac{nV}{Q}$. Cum igitur valor rectæ PH non pendeat a quantitatibus $l$, $k$ et $r$; ſed, his mutatis, ſit ſemper idem, erit punctum $\mu$ ad rectam poſitione datam, ut in Theor. 4. aliter oſtendimus. Quin & valor rectæ PH is eſt quem in Art. 29. alia methodo definivimus; & recta $Hm$ om-





$\frac{lu}{r}$, *in quantitate* $Py = a^{n-1} + b^{n-1}$

$\times xy$; *& termini resultantes sibi*

$+ bz^{n-2} + cz^{n-3}$ *&c.* $x = \frac{b}{r}$ *fiunt*

*Supponatur nunc* $z = s$, *& termin*

*lis* $V = \frac{Qlu}{r}$ *& posteriorum summ*

*anifestum est ultimum terminum eor*

$V$, *& penultimum* $pu = \frac{Pl \pm Ql}{r}u$

*it nunc Pμ medium harmonicum in*

, $PE$, $PL$, *&c. ex* $P\mu$ *medium harm*

*nta* $Pd$, $Pe$, $P\delta$, *&c. ut in Art.* 3. *u*

*ficillam in* $H$; *& supponamus* $P_s$ *eas*

*am esse. Ducatur* $\mu\sigma$ *abscindens prima*

*occurrens in* $rs$, *eritque* $Ps$ *ad* $P\mu$ *ut*

*ad* $r$, *ut* $\mu\sigma$ *ad* $P\mu$ *ut* $A$ *ad* $r$. *Cum*

per Articulum præcedentem) $\frac{nV}{Pl \pm Ql}$

$Ps = \frac{nV}{P} \pm \frac{nvl}{pr} = \frac{nV}{P} \pm \frac{nV}{Pl \pm Ql}$

*Est autem ms ad* $s\mu$ *ut Pm ad PH*;

ad $\frac{nVt}{Pl \pm Ql}$ ut $Pm$ *ad* $PH$; *unde*

$PH$, *vel* $PH = Pm \times \frac{P}{Q}$ *vel* $\frac{nV}{Q}$. *Ca*

*ne* $PH$ *non pendeat a quantitatibus*

*mutatis, fit semper idem, erit punctu*

*finitione datum, ut in Theor. 4. sim*

*inin & valor rectæ* $PH$ *is est quem*

*thodo definimus; & recta linea*





nes rectas ex P ductas secat harmonice, secundum definitionem sectionis harmonicæ in Art. 28. generaliter propositam.

## SECTIO II.

### *De Lineis secundi ordinis, sive sectionibus conicis.*

§ 33. EX iis quæ generaliter de lineis geometricis in sectione primâ demonstrata sunt, sponte fluunt proprietates linearum secundi, tertii, & superiorum ordinum. Quæ ad sectiones conicas spectant optime derivantur ex proprietatibus circuli, quæ figura basis est coni. Verum ut usus theorematum præcedentium clarius pateat, & figurarum analogia illustretur, operæ pretium erit harum quoque affectiones ex præmissis deducere. Doctrina autem conica de diametris, earumque ordinatis (quibus parallelæ sunt rectæ sectionem contingentes ad vertices diametri) & de parallelarum segmentis quæ rectis quibuscunque occurrunt, & asymptotis, tota facillime fluit ex iis quæ Art. 4. & 5. ostensa sunt.

§ 34. Rectæ AB & FG sectione conicæ inscriptæ occurrant sibi mutuo in puncto P; ductæ AK, BL, FM, GN sectionem contingentes occurrant rectæ PE, per P ductæ in punctis K, L, M, N; eritque semper $\frac{1}{PK} \pm \frac{1}{PL} = \frac{1}{PM} \mp \frac{1}{PN}$ (si recta PE curvæ occurrat in punctis D & E) $= \frac{1}{PD} \mp \frac{1}{PE}$. Segmentis autem

Fig. 20.

tem quæ ſunt ad eaſdem partes puncti P eadem præponuntur ſigna; iiſque quæ ſunt ad oppoſitas partes
Fig. 21. puncti P ſigna præponuntur contraria. Hinc ſi biſecetur DE in P, & ex puncto P ducatur recta quævis ſectionem ſecans in punctis A et B, unde ducantur rectæ AK et BL curvam contingentis quæ rectam DE
Fig. 22. ſecent in K et L; erit ſemper PK = PL. Quod ſi DE ſectioni non occurrat, ſitque P punctum ubi diameter quæ biſecat rectas ipſi DE parallelas eidem occurrit; erit in hoc quoque caſu PK = PL.

Fig. 23. § 35. Concurrant rectæ AB et FG ſectioni conicæ inſcriptæ in puncto P; ducantur rectæ ſectionem contingentes in punctis A et F quæ ſibi mutuo occurrant in K, & juncta PK tranſibit per occurſum rectarum quæ ſectionem contingunt in punctis B et G. Si enim recta PK non tranſeat per occurſum rectarum ſectionem tangentium in B et G, huic occurrat in N illi in L; cumque $\frac{1}{PK} \mp \frac{1}{PL} = \frac{1}{PK} \mp \frac{1}{PN}$ per præcedentem, erit PL = PN; & coincidunt puncta L et N contra hypotheſin.

§ 36. Eadem ratione patet rectas AG et BF ſibi mutuo occurrere in $\pi$ puncto rectæ LK; adeoque puncta P, K, $\pi$, L eſſe in eadem recta linea. Hinc datis tribus punctis contactus A, B, et F, cum duabus tangentibus AK et FK, ſectio conica facile deſcribitur. Revolvatur enim recta K$\pi$P circa tangentium occurſum K ut polum, quæ occurrat rectis AB et FB in punctis P et $\pi$; & junctæ A$\pi$, FP occurſo ſuo G deſcribent ſectionem conicam quæ tranſibit per tria puncta data A, B, F & continget rectas AK et FK in A et F.

§ 37.

*ſunt ad eaſdem* partes puncti P eadem po
*na; iiſque quæ ſunt ad oppoſitas* pa
*ignа præponuntur* contraria. Hinc in
*in P, & ex puncto P* ducatur recta qua
*ecans in punctis* A et B, unde ducantur
*BL curvam* contingentia quæ rectæ
*et L; erit ſemper* PK = PL. Qua
non occurrat, ſitque P punctum ab
bifecat rectas ipſi DE parallelas un
*it in hoc quoque caſu* PK = PL.

*currant rectæ* AB et FG ſectioni coni
*uncto P;* ducantur rectæ ſectionem
*punctis* A et F quæ ſibi mutuo occur
*ctæ* PK tranſibit per occurſum rectæ
*a contingunt in punctis* B et G. Sim
*tranſeat per occurſum* rectarum fic
*um in* B et G, huic occurrat in N: a
$\frac{1}{PK} \mp \frac{1}{PL} = \frac{1}{PK} \mp \frac{1}{PN}$ per pro
$PL = PN$; & coincidunt puncta L e
*othesin.*

*ratione* patet rectas AG et BF in
*e in* π puncto rectæ LK; atque
, L *eſſe in* eadem recta linea. Hinc
*ctis contactus* A, B, et F, cum duabus
*et* FK, ſectio conica facile describitur
*recta* K π P circa tangentium occur
*, quæ occurrat* rectis AB et FB in
*& junctæ* Aπ, FP occurſo ſuo G
*cum conicam* quæ tranſibit per tria
, F *& continget* rectas AK et FK in

§ 3



Appen. pa. 31.

Fig. 26.




Fig. 2

Fig. 24.

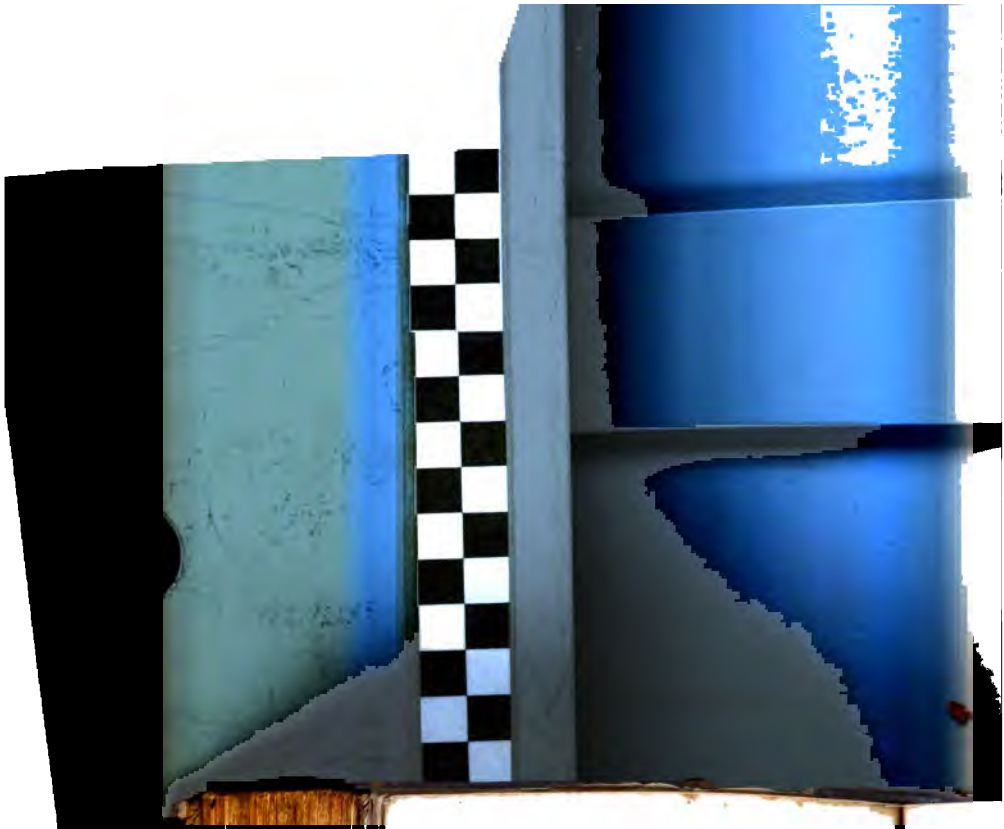
§ 37. Cæteris manentibus, occurrant rectæ AF et BG mutuo in puncto $p$, tangentes AK et BL in R, que tangentes FK et GL in Q; & puncta R, $\pi$, Q, $p$ erunt in eadem recta linea; similiter occurrant tangentes AK et GQ in $m$; tangentes BR et FK in $n$; puncta P; $m$, $n$, $p$ erunt in eadem recta linea. Demonstratur ad modum Art. 35.

§ 38. Hinc datis quatuor punctis contactus A, B, F, G cum unica tangente AK, occursus rectarum AB et FG, AF et BG, atque AG et BF, dabunt puncta P, $p$, et $\pi$; junctæ autem P$p$, P$\pi$, et $p\pi$ secabunt tangentem datam AK in tribus punctis $m$, K et R unde ductæ $m$G, KF, RB sectionem conicam contingent in punctis datis G, F et B.

§ 39. Datis quatuor tangentibus RK, KQ, QL, LR et unico puncto contactus A, occursus tangentium RK et LQ, LR et QK dabunt puncta $m$ et $n$. Jungantur LK et $mn$; & occursus rectarum LK et RQ, LK et $nm$, RQ et $nm$, dabunt puncta $\pi$, P et $p$; junctæ vero PA, $\pi$A et $p$A secabunt tangentes RL, QK et QL in punctis contactus B, G et F.

§ 40. Datis quinque punctis contactus A, B, F, G, et $f$, junctæ GF et G$f$ rectæ AB occurrant in punctis P et X; junctæ AF et A$f$ occurrant rectæ BG in $p$ et $x$; & junctæ P$p$, X$x$ occursu suo dabunt punctum $m$; unde ductæ $m$A et $m$G sectionem conicam tangent in A et G; & similiter determinantur rectæ quæ curvam contingent in punctis reliquis B, F et $f$.

§ 41. Dentur quinque rectæ sectionem conicam contingentes, VK, KQ, QL, L$\omega$, et $\omega$V; occursus tangentium VK et LQ dabit punctum $m$; occursus tangentium KQ





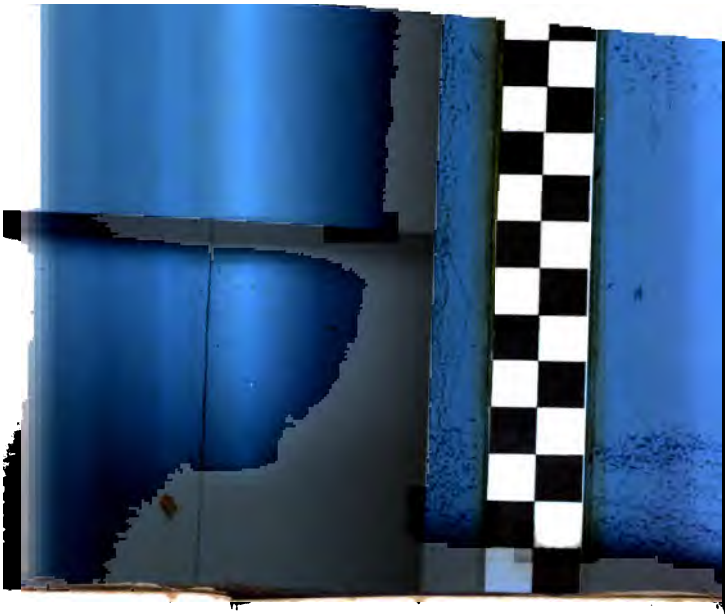
KQ et *Lu*, dabit punctum $\pi$; jungantur $m\pi$, LK, VL et $m\mu$; recta LK secabit rectam $m\pi$ in P; & recta I,V secabit ipsam $m\mu$ in X; juncta autem PX secabit tangentes VK et $\mu L$ in punctis contactus A et B. Similiter reliqua puncta contactus determinantur.

Fig. 25. § 42. Datis tribus tangentibus AK, BK, et RL, cum duobus punctis contactus A et B; facillime determinatur tertium, per Art. 35. Occurrat enim tangens RL reliquis tangentibus in R et L, atque junctæ AL et BR, se mutuò decussent in $\pi$, juncta K$\pi$ secabit tangentem RL in tertio puncto contactus F; & sectio conica describi potest ut in Art. 36.

Fig. 26. § 43. Detur quatuor tangentes KQ, QL, LR, et RK cum unico puncto D sectionis conicæ quod non sit in aliquâ quatuor tangentium. Inveniantur puncta P, $\rho$ et $\pi$ ut in Art. 39. Jungantur PD, $\rho$D, et $\pi$D; & ducta PZ rectæ $\rho$D parallela occurrat rectæ RQ in Z; & bifariam secetur PZ in S; & ducta $\rho$S secabit rectam PD in E puncto curvæ vel occurrat PD rectæ RQ in $\varepsilon$, et (per Art. 23.) secetur PD harmonice in $\varepsilon$ et E. Ducta autem D$\pi$ secabit junctam $\rho$E in $\epsilon$, et E$\pi$ secabit ipsam $\rho$D in $\delta$, ità ut hæc quoque puncta $\delta$, $\epsilon$ sint ad curvam.

Fig. 27, n. 1. § 44. Ex puncto R ducantur duæ tangentes ad sectionem conicam in A et B; ex puncto A ducantur rectæ duæ AF et AG sectioni occurrentes in F et G; juncta BG secet AF in P, et juncta BF secet rectam AG in $\pi$; eruntque puncta P, K, $\pi$ in eadem rectâ linea, per Art. 36.

n. 2. Verum propositio hæc generalior est. Si enim a puncto quovis K ducantur duæ rectæ K*Aa*, K*Bb* sectionem





Q et Lm. dabit punctum π; jungantur mL, mn; recta LK secabit rectam mn in P, & ita abit ipsam mπ in X; juncta autem PI tan tes VK et mL in punctis contactus A et B, qua puncta contactus determinantur.

42. Datis tribus tangentibus AK, BK, et L us punctis contactus A et B, facillime deme m, per Art. 35. Occurrat enim tangen tangentibus in R et L, atque juncta LB tuo decussent in π, juncta Kπ secabit tan tertio puncto contactus F; & facta con poteſt ut in Art. 36.

Dentur quatuor tangentes KQ, QL, R im unico puncto D sectionis conicæ quæ uâ quatuor tangentium. Inveniantur p ut in Art. 39. Jungantur PD, pD, et Z rectæ pD parallela occurrat rectæ RQ sit secetur PZ in S; & ducta pS secabit E puncto curvæ; vel occurrat PD rectæ per Art. 23.) secetur PD harmonice in tum autem Dπ secabit junctam pL in σ, et B dam pD in d, ita ut hæc quoque punct urvam.

Ex puncto K ducantur duæ tangentes K conicam in A et B; ex puncto A tangen AF et AG sectioni occurrentes in F et G secet AF in P, et juncta BF secet recta ; erunt que puncta P, K, π in eadem Art. 36.

propositio hæc generalior est. Si ex ovis K ducantur duæ rectæ KAa, KBb



ctionem secantes in punctis A, a et B, b; et ex punctis A et a ducantur rectæ & sectionem AF et aG; juncta autem BF secet aG in P, & ducta bG secet AF in π; erunt puncta P, K, π in eadem recta linea; quod variis modis aliàs demonstravimus, unde expeditam methodum olim deduximus sectionem conicam describendi per data quævis quinque puncta. Sint A, a, B, b et F puncta quinque data; concurrant rectæ Aa et Bb in K; jungantur AF et BF; revolvatur recta PKπ circa polum K, quæ occurrat his rectis in π et P; et ductæ aP, bπ concursu suo G sectionem describent.

§ 45. Sit P punctum datum extra sectionem coni- Fig. 28.
cam, unde ducta quævis sectioni occurrat in D et E; et si $\frac{2}{PM} = \frac{1}{PD} \mp \frac{1}{PE}$ erit M ad lineam rectam AB quæ sectioni occurrit in punctis A et B, ita ut ductæ PA et PB, erunt contingentes sectionis. Si vero punctum p sit in medio puncto rectæ AB intra sectionem, sitque $\frac{2}{pm} = \frac{1}{pd} \mp \frac{1}{pe}$, locus puncti m erit recta ab per P ducta ipsi AB parallela. Tangentes ad puncta D et E semper concurrunt in recta AB, et tangentes ad puncta d et e in recta ab.

§ 46. Contingat recta DT sectionem in D, undè du- Fig. 29.
cantur duæ quævis rectæ DE et DA, quæ sectioni occurrant in E et A. Occurrat DE rectæ AK sectionem contingenti, in K; et ductæ EN, KM tangenti DT parallelæ secent DA in N et M, sumatur in rectæ DE, DR ad EN ut KM ad KE, & circulus ejusdem curvaturæ cum sectione in D transibit per R. Nam per Art. 15. est $\frac{QV^2}{DV^2 \times DR} = \frac{}{DE} = \frac{}{DK} = \frac{KE}{DE \times DK}$ et

DR

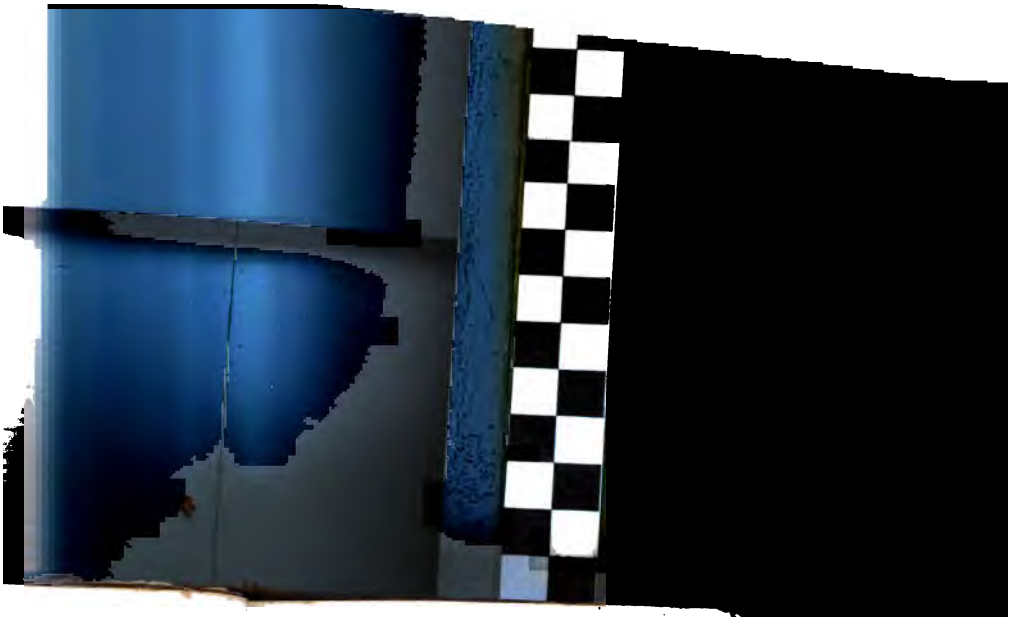
KQ et Lκ dabit punctum π; jungantur mκ, LK, VL et mκ; recta LK secabit rectam mκ in P; & recta LV secabit ipsam mκ in X; juncta autem PX secabit tangentes VK et κL in punctis contactus A et B. Similiter reliqua puncta contactus determinantur.

Fig. 25. § 42. Datis tribus tangentibus AK, BK, et RL, cum duobus punctis contactus A et B, facillime determinatur tertium, per Art. 35. Occurrat enim tangens RL reliquis tangentibus in R et L, atque junctæ AL et BR, se mutuo decussent in π, juncta Kπ secabit tangentem RL in tertio puncto contactus F; & sectio conica describi potest ut in Art. 36.

Fig. 26. § 43. Dentur quatuor tangentes KQ, QL, LR, et RK cum unico puncto D sectionis conicæ quod non sit in aliquâ quatuor tangentium. Inveniantur puncta P, ρ et π ut in Art. 39. Jungantur PD, ρD, et πD; & ducta PZ rectæ ρD parallela occurrat rectæ RQ in Z; & bifariam secetur PZ in S; & ducta ρS secabit rectam PD in E puncto curvæ; vel occurrat PD rectæ RQ in κ, et (per Art. 23.) secetur PD harmonice in z et E. Ducta autem Dπ secabit junctam ρE in e, et Eπ secabit ipsam ρD in d, ita ut hæc quoque puncta d, e sint ad curvam.

Fig. 27, n. 1. § 44. Ex puncto K ducantur duæ tangentes ad sectionem conicam in A et B; ex puncto A ducantur rectæ duæ AF et AG sectioni occurrentes in F et G; juncta BG secet AF in P, et juncta BF secet rectam AG in π; erunt que puncta P, K, π in eadem recta linea, per Art. 36.

n. 2. Verum propositio hæc generalior est. Si enim a puncto quovis K ducantur duæ rectæ KAα, KBβ sectionem





$= \frac{DE \times DK}{KE} \times \frac{QV^2}{DV^2}$ (quoniam QV : V

: DK :: EN : DE) $= \frac{KM \times EN}{KE}$ (qu

tangens AK parallela rectæ DE, (i.e. à

a diametri per A transeuntis) erit DK $= \frac{}{2}$

ad DE ut $EN^2$ ad $DE^2$; ut alibi demon

: 373. tractatus de fluxionibus. Si in hac

diameter, erit $\frac{EN^2}{DE}$, adeoque DR, æqua

diametri DE; ut satis notum est.

Ducantur rectæ DT, DE, quarum pri

cam contingat in D, posterior cidem occ

ducatur DA quæ bisecet angulum EDT

urrat in A; jungatur AE, cui occurrat

parallela rectæ quæ curvam contingit

parallelà rectæ DA, hæc secabit DK ubi

culatorius occurrit rectæ DE; eritque K

urvaturæ si angulus EDT fit rectus

ad AD ut ER ad DE, et ut DR ad DK, ac

K ut DE ad EK, adeoque $\frac{1}{DR} = \frac{}{DK}$

ortebat, per Art. 15. Si autem fi tange

la rectæ DE (quo in casu tangentes AK

s constituunt angulos cum rectâ DA ac

endicularis est axi figuræ) coincident punc

circulus osculatorius transibit per punctu

r quoque ex dictis rectas EK, DE, et D

ffione geometrica.

urrat recta quævis DE sectioni conicæ in

rant rectæ curvam contingentes ad D



in puncto V. Sit DOA diameter per D curvæ, & si constituatur angulus DV$r$ = EDO, erit DR (= 2D$r$) chorda circuli osculatorii. Ducatur enim AK sectionem contingens quæ rectæ DE occurrat in K, et tangenti EV in Z; ducatur EN parallela tangenti DT rectam DA secans in N; cumque sit DR ad KA ut EN ad EK; sitque KZ (= $\frac{1}{2}$AK) ad EK ut VD ad DE, erit VD ad DE ut $\frac{1}{2}$DR ad EN; adeoque triangula DV$r$ et EDN similia et angulus DV$r$ æqualis angulo EDO. Hanc methodum determinandi circulum osculatorium demonstravimus in tractatu de fluxionibus, Art. 375. sed non adeo breviter.

§ 49. Variatio curvaturæ, sive tangens anguli contactus sectione conica & circulo osculatorio comprehensi, est directe ut tangens anguli contenti diametro quæ per contactum ducitur & normali ad curvam, & inverse ut quadratum radii curvaturæ. Sit enim DR diameter curvaturæ, & hæc variatio ad punctum D erit ut $\frac{1}{DR \times DV}$, per Art. 17. adeoque, cum sit DV ad D$r$ ut DE ad EN, ut $\frac{EN}{DE \times DR^2}$. Variatio autem radii curvaturæ est ut tangens anguli EDO. Quod si recta DO circulo osculatorio occurrat in $n$, parabola diametro & parametro D$n$ describta, quæque contingit rectam DT in D, ea erit cujus contactus cum sectione est intimus, per Art. 19. Fig. 32.

§ 50. Cæteris manentibus, ex puncto V ducatur recta VH circulum osculatorium contingens in H; jungatur HD, cumque sit angulus RDH complementum anguli D$r$V ad rectum, erit RDH = DV$r$ = EDO; adeoque variatio radii curvaturæ erit ut tangens anguli RDH; Fig. 32.

RDH; & coincidentibus rectis DR et DH variatio evaneſcit.

## SECTIO III.

### *De Lineis tertii Ordinis.*

§ 51. DE lineis tertii ordinis ſive curvis ſecundi generis, uberius nobis agendum eſt. Doctrinam conicam, variis modis uſque ad faſtidium fere, tractarunt permulti. Hanc autem geometriæ univerſalis partem, pauci adtigerunt; eam tamen nec ſterilem eſſe nec injucundam ex ſequentibus, ut ſpero, patebit, cum præter proprietates harum figurarum a *Newtono* olim traditas, aliæ ſunt plures geometrarum attentione non indignæ. Oſtendimus ſupra, rectam ſecare poſſe lineam tertii ordinis in tribus punctis, quoniam æquationis cubicæ tres ſunt radices, quæ omnes reales eſſe poſſunt. Recta autem quæ lineam tertii ordinis in duobus punctis ſecat, eidem in tertio aliquo puncto neceſſario occurrit, vel parallela eſt aſymptoto curvæ, quo in caſu dicitur ei occurrere ad diſtantiam infinitam: æquationis enim cubicæ ſi duæ radices ſint realis, tertia neceſſario realis erit. Hinc recta quæ lineam tertii ordinis contingit, eam in aliquo puncto ſemper ſecat; cum contactus pro duabus interſectionibus coincidentibus habendus ſit. Recta autem quæ curvam in puncto flexus contrarii contingit, ſimul pro ſecante habenda eſt. Ubi duo arcus curvæ ſibi mutuo occurrent, punctum *duplex* formatur, & recta quæ alterum arcum ibi tangit in eodem puncto alterum ſecat.

*I*; & coincidentibus rectis DR et DI cum

fcit.

## SECTIO III.

### *De Lineis tertii Ordinis.*

DE lineis *tertii ordinis* five curvis ejus *generis*, uberius nobis agendum eſt. Ju*onicam*, variis modis uſque ad ſatietatem permulti. Hanc autem geometrice cu*n*, pauci adtigerunt; eam tamen ac hæ*ec injucundam ex ſequentibus, ut ſpe*ro *im præter proprietates harum figurarum lim traditas, aliæ ſunt plures generum* ipſon indignæ. Oſtendimus ſupra, rectam*neam tertii ordinis in tribus punctis, ea*ionis cubicæ tres ſunt radices, quæ unæ poſſunt. Recta autem quæ lineam ter*robus punctis ſecat, eidem in tertio non* ſſario occurrit, vel parallela eſt ſtrictus *in caſu dicitur ei occurrere ad infinitum* quationis enim cubicæ ſi duæ radices ſi*neceſſario realis erit. Hinc recta quæ* ordinis contingit, eam in aliquo puncto cum contactus pro duabus interſectionibus habendus ſit. Recta autem quæ *cto flexus contrarii contingit, ſimul per*a eſt. Ubi duo arcus curvæ ſibi mutuo *ctum duplex formatur, & recta quæ ei*bi tangit in eodem puncto alterum

ſecat.

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ſecat. Recta autem alia quævis ex puncto duplice ducta in uno alio puncto curvam ſecat, ſed non in pluribus.

§ 52. PROP. I. Sint duæ parallelæ, quarum utraque ſecet lineam tertii ordinis in tribus punctis; recta quæ utramque parallelam ita ſecat ut ſumma duarum partium parallelæ ex uno ſecantis latere ad curvam terminatarum æqualis ſit tertiæ parti ejuſdem ex altero ſecantis latere ad curvam terminatæ ſimiliter ſecabit omnes rectas his parallelas quæ curvæ in tribus punctis occurrunt; per Art. 4.

§ 53. PROP. II. Occurrat recta poſitione data lineæ tertii ordinis in tribus punctis; ducantur duæ quævis parallelæ quarum utraque curvam ſecet in totidem punctis; & ſolida contenta ſub ſegmentis parallelarum ad curvam & rectam poſitione datam terminatis erunt in eadem ratione ac ſolida ſub ſegmentis hujus rectæ ad curvam & parallelas terminatis, per Art. 5.

Hæ duæ proprietates a *Newtono* olim expoſitæ fuerunt.

§ 54. PROP. III. Cæteris manentibus ut in propoſitione præcedente, occurrat recta poſitione data lineæ tertii ordinis in unico puncto A, & ſolidum ſub ſegmentis PM, $Pm$, $P\mu$ unius parallelæ contentum erit ſemper ad ſolidum ſub ſegmentis $pN$, $pn$, $p\nu$, alterius parallelæ ut ſolidum $AP \times bP^2$ contentum ſub ſegmento AP & quadrato Fig 3.

drato diſtantiæ $bP$ puncti P a puncto quodam $b$ ad ſolidum $Ap \times bp^2$ contentum ſub ſegmento $Ap$ et quadrato diſtantiæ puncti $p$ ab eodem puncto $b$, per Art. 6.

Fig. 34. n. 1. § 55. PROP. IV. Ex dato quovis puncto P ducatur recta PD quæ lineæ tertii ordinis occurrat in tribus punctis D, E, F, & alia quævis recta PA quæ eandem ſecet in tribus punctis A, B, C. Ducantur tangentes AK, BL, CM, quæ rectæ PD occurrant in K, L, et M; et medium harmonicum inter tres rectas PK, PL, PM, coincidet cum medio harmonico inter tres rectas PD, PE, et PF, per Art. 10. & 28. Si autem n. 2. recta PD curvæ occurrat in unico puncto D, inveniatur punctum $d$ ut in Art. 6. & medium harmonicum inter tres rectas PK, PL, PM, erit ad medium harmonicum inter duas rectas PD et $\frac{2}{3}$ P$d$ in ratione 3 ad 2, per Art. 12.

§ 56. PROP. V. Revolvatur recta PD circa polum P, ſumatur ſemper PM in recta PD æqualis medio harmonico inter tres rectas PD, PE, et PF, eritque locus puncti M linea recta, per Art. 28.

Atque hæc eſt proprietas harum linearum a *Cotſio* inventa.

Fig. 35. § 57. PROP. VI. Sint tria puncta lineæ tertii ordinis in eadem recta linea; ducantur rectæ curvam in his punctis contingentes, quæ eandem

ſecent

distantiæ $bP$ puncti P a puncto quoni
lidum $Ap \times bp^2$ contentum sub figura
quadrato distantiæ puncti $p$ ab eo
$b$, per Art. 6.

5. Prop. IV. Ex dato quovis punct
ar recta PD quæ lineæ tertii ordinis
in tribus punctis D, E, F, & alia quæ
A quæ eandem secet in tribus punctis
Ducantur tangentes AK, BL, CM, qu
D occurrant in K, L, et M; et medio
icum inter tres rectas PK, PL, PM c
cum medio harmonico inter tres rec
, et PF, per Art. 10. & 28. Si aut
curvæ occurrat in unico puncto D, a
punctum $d$ ut in Art. 6. & mediu
um inter tres rectas PK, PL, PM, et
m harmonicum inter duas rectas PD
tione 3 ad 2, per Art. 12.

Prop. V. Revolvatur recta PD circ
fumatur semper PM in recta PD
dio harmonico inter tres rectas PD,
, eritque locus puncti M linea recta,
.

: est proprietas harum linearum a Cæp

op. VI. Sint tria puncta lineæ tr
eadem recta linea; ducantur rectæ
s punctis contingentes, quæ eandem
secent

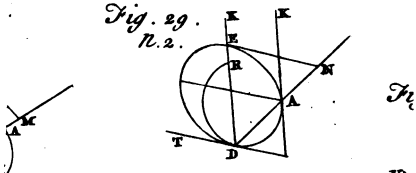


Fig. 29. n. 2.

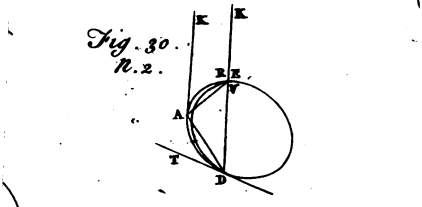


Fig. 30. n. 2.

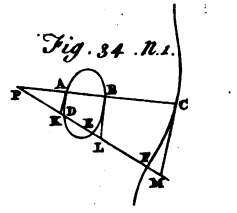
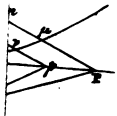


Fig. 34. n. 1.




36.

Fig.
n. 1.

9. 31

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ſecent in aliis tribus punctis; atque hæc tria puncta erunt etiam in recta linea.

Occurrat recta FGH lineæ tertii ordinis in tribus punctis F, G, et H. Rectæ FA, GB, HC, curvam in his punctis contingentes eandem ſecent in punctis A, B, C; & hæc puncta erunt in recta linea. Jungatur enim AB, & hæc tranſibit per C; ſi enim fieri poteſt, occurrat curvæ in alio puncto M, tangenti HC in N et rectæ FGH in P; cumque ſit $\frac{1}{PA} + \frac{1}{PB} + \frac{1}{PM} = \frac{1}{PA} + \frac{1}{PB} + \frac{1}{PN}$, per Prop. IV. erit PN = PM; quod fieri nequit niſi coincidant puncta N, M, et C. Recta igitur AB tranſit per C.

§ 58. *Corol.* Hinc ſi A, B, C, ſint tria puncta lineæ tertii ordinis in eadem recta linea, ductæ autem AF et BG curvam contingant in F et G, & juncta FG curvam denuo ſecet in H, juncta CH curvam continget in H. Si enim recta curvam contingeret in H quæ eandem ſecaret non in C ſed in alio quovis puncto, foret hoc punctum cum tribus aliis A, B, C, in eadem recta quæ igitur ſecaret lineam tertii ordinis in quatuor punctis. Hoc autem fieri non poteſt. Incidi autem primo in hanc propoſitionem via diverſa ſed minus expedita, eandem deducendo ex Prop. II. Similiter ſi recta *Af* curvam quoque contingat in *f*, & ducta *Gf* curvæ occurrat in *h*, juncta *Ch* erit tangens ad punctum *h*. Et ſi a punctis A, B, C, lineæ tertii ordinis in eadem recta ſitis, ducantur tot rectæ curvam contingentes quot duci poſſunt, erunt ſemper tres contactus in eadem rectâ.

§ 59. Prop. VII. Ex puncto quovis lineæ tertii ordinis ducantur duæ rectæ curvam con- Fig. 36.

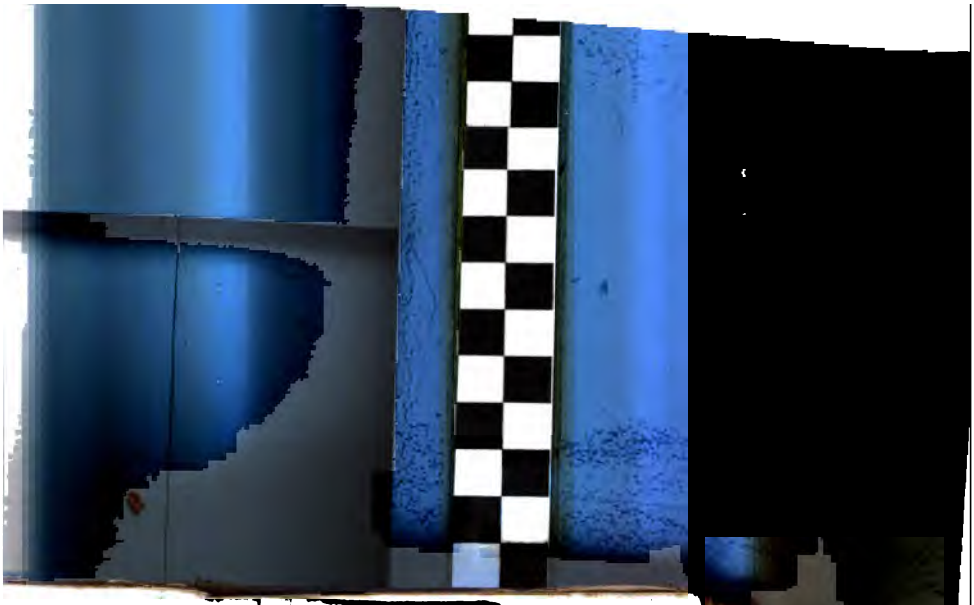
tingentes, & recta contactus conjungens denuo secet curvam in alio puncto, rectæ curvam in hoc puncto & in primo puncto contingentes se mutuo secabunt in puncto aliquo curvæ.

Ex puncto A ducantur rectæ curvam contingentes in F et G, juncta FG curvam secet in H, eandemque contingat in H recta HC quæ curvæ occurrat in C, & ducta AC erit curvæ tangens ad punctum A. Sequitur ex *Corollario* præcedente, coincidentibus enim A et B recta CA fit tangens ad punctum A.

§ 60. *Corol.* 1. Si ex puncto curvæ C ducantur duæ rectæ eandem contingentes in A et H, & ex puncto alterutro A contingentes AF et AG ad curvam, recta per contactus F et G ducta transibit per alterum punctum H.

Fig. 37. § 61. *Corol.* 2. Contingat recta AC curvam in A, eamque secet in C, ductæ autem AF et CH curvam contingant in F et H, recta per contactus ducta eam denuo secet in G, & juncta AG curvam continget in G. Quod si alia recta C*b* ex puncto C ducatur ad curvam eam contingens in *b*; & junctæ *b*F, *b*G, curvæ occurrant in *f* et *g*, ductæ A*f* et A*g* erunt tangentes ad puncta *f* et *g*.

Fig. 38. § 62. *Corol.* 3. Sit A punctum flexus contrarii unde ductæ AF et AG curvam contingant in F et G juncta FG secet curvam in H, & ducta AH curvam continget in H. Si enim tangens ad punctum H curvæ in alio quovis puncto ab A diverso occurreret, recta ex hoc occursu ad punctum flexus contrarii A ducta curvam in A contingeret, quot fieri nequit. Manifestum autem est tres tantum duci posse rectas ex puncto flexus contrarii curvam





s, & recta contactus conjungens su
vam in alio puncto, rectæ curvæ
cto & in primo puncto contingen
cabunt in puncto aliquo curvæ.

o A ducantur rectæ curvam contingen
ecta FG curvam secet in H, cuius
H recta HC quæ curvæ occurrat in
it curvæ tangens ad punctum A. Sect
præcedente, coincidentibus enim hi
tangens ad punctum A.

1 Si ex puncto curvæ C ducantur
contingentes in A et H, & ejus
tangentes AF et AG ad curvam, ta
et G ducta transibit per alternæ

Contingat recta AG curvam in
, ductæ autem AF et CH curv
H, recta per contactus ducta
& junctæ AG curvam continget
ecta Ch ex puncto C ducatur
ens in h; & junctæ hF, hG, te
g, ductæ Af et Ag erunt ta
g.

A punctum flexus contrarii ine
am contingant in F et G junct
& ducta AH curvam continget
s ad punctum H curvæ in alio
rso occurreret, recta ex hoc oc-
contrarii A ducta curvam in
quit. Manifestum autem est
tas ex puncto flexus contrarii
curvam



Fig. 37.

Fig 3

Fig 5

curvam contingentes præter eam quæ in hoc ipſo puncto ſimul tangit & ſecat, atque tres contactus cadere in eandem rectam lineam. Ex ſolo puncto flexus contrarii tres rectæ ductæ curvam ita contingunt ut tres contactus ſint in eadem rectâ. Sint enim F, G, H, in eadem recta, unde tangentes ductæ conveniant in eodem puncto curvæ *a*, quod non ſit punctum flexus contrarii; ducatur *ae* curvam contingens in *a*, quæque ei occurrat in *e*, & juncta *e*H curvam tanget in H, per hanc propoſitionem; adeoque rectæ *e*H et *a*H curvam contingerent in eodem puncto H. *q. e. a.*

§ 63. PROP. VIII. Ex puncto quovis lineæ tertii ordinis ducantur tres rectæ curvam contingentes in tribus punctis; recta duos quoſvis contactus conjungens occurrat denuo curvæ, & ex occurſu ad tertium contactum ducta curvam denuo ſecabit in puncto ubi recta ad primum punctum ducta curvam continget.

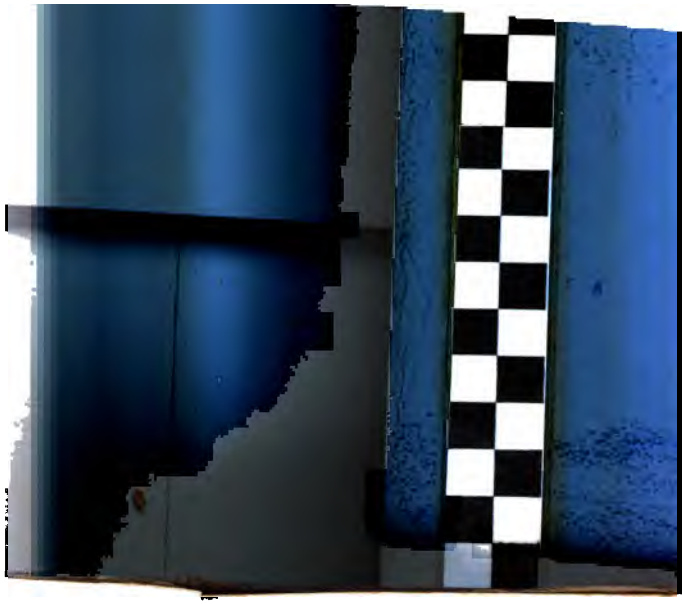
Ex puncto A, lineæ tertii ordinis ducantur tres rectæ AF, AG, et A*f*, curvam contingentes in tribus punctis F, G, et *f*; recta G*f* quæ horum duo quævis conjungit ſecet curvam denuo in N, et recta ex hoc puncto ad tertium contactum F ducta curvam ſecet in *g*, tum juncta A*g* curvam continget in *g*. Ducatur enim recta AC curvam contingens in A quæ eandem ſecet in C; cumque puncta G, N, et *f*, ſint in eadem recta, & tangentes ad puncta G et *f* tranſeant per A, ſequitur (per Prop. VII.) tangentem ad punctum N tranſire per C. Cumque puncta F, N, *g*, ſint in eadem rectâ, tangentes autem FA et NC curvæ occurrant in A et C, ſitque AC tangens ad punctum A, tangens ad punctum *g* tranſibit per A. Fig. 37.

§ 64. *Corol.* Hinc ſi curva deſcribatur, ex datis tribus punctis contactus ubi tres rectæ ex eodem puncto curvæ ductæ eam contingunt, invenitur quartum punctum contactus ubi recta ex eodem puncto curvæ ducta eam contingit. Atque hinc colligitur ex eodem curvæ puncto quatuor tantum rectas duci poſſe lineam tertii ordinis contingentes præter rectam quæ in hoc ipſo puncto curvam contingit. Si enim rectæ ex eodem curvæ puncto duci poſſent eam in quinque punctis contingentes, plures rectæ numero indefinitæ curvam contingentes ex eodem puncto duci poſſent; ut ex præmiſſis facile colligitur. Hoc autem Corollarium poſtea facilius demonſtrabitur. Vide infra, Art. 77.

Fig. 58. § 65. PROP. IX. Ex puncto flexus contrarii ducantur tres tangentes ad curvam, & recta contactus conjungens harmonice ſecabit rectam quamvis ex puncto flexus contrarii ductam & ad curvam terminatam.

Sit A punctum flexus contrarii, AF, AG, et AH, rectæ curvam contingentes in punctis F, G, et H. Ex puncto A ducatur recta quævis curvam ſecans in B et C, & rectam FH in P; eritque PB ad PC ut BA ad AC. Cum enim tres tangentes ad puncta F, G, et H, in eodem puncto A conveniant, erit per Prop. IV. $\frac{1}{BP} + \frac{1}{PA} - \frac{1}{PC} = \frac{3}{PA}$, adeoque $\frac{1}{PB} - \frac{1}{PC} = \frac{2}{PA}$, i. e. PA eſt medium harmonicum inter duas rectas PB et PC ad curvam terminatas. Quæ linearum tertii ordinis proprietas eſt ſimplicitatis inſignis.

§ 66.





*Corol.* Hinc ſi curva deſcribatur, ex data
lis contactus ubi tres rectæ ex eodem pu
ctæ eam contingunt, invenitur quartus p
actus ubi recta ex eodem puncto curvæ
igit. Atque hinc colligitur ex eodem co
atuor tantum rectas duci poſſe lineas re
ntingentes præter rectam quæ in hoc
vam contingit. Si enim rectæ ex eod
cto duci poſſent eam in quinque pun
s, plures rectæ numero indefinito curva
ex eodem puncto duci poſſent; ut ex p
colligitur. Hoc autem Corollarium pote
ſtrabitur. Vide infra, Art. 77.

OP. IX. *Ex puncto flexus contr*
s *tangentes ad curvam, & reli*
*ungens harmonice ſecabit reliq*
*ncto* flexus contrarii ducta *ad*
*iatam.*

*flexus contrarii, AF, AG, et AH,*
*tingentes in punctis F, G, et H. Et*
*recta quævis curvam ſecans in BbC,*
*; eritque PB ad PC ut BA ad AC.*
entes ad puncta F, G, et H, inter-
*niant, erit per Prop. IV.* $\frac{1}{BP}+\frac{1}{PA}$
*que* $\frac{1}{PB}-\frac{1}{PC}=\frac{2}{PA}$, *i.e. PA*
*am inter duas rectas PB et PC ad*
Quæ linearum tertii ordinis pro-
*inſignis.*

§ 66.



§ 66. *Corol.* 1. Recta quæ duas quaſvis rectas ex puncto flexus contrarii ductas ad curvam ſecat harmonice, ſecabit quoque alias quaſvis rectas ex eodem puncto eductas & ad curvam terminatas.

§ 67. *Corol.* 2. Si recta aſymptoto parallela per punctum flexus contrarii ducta occurrat rectæ FH in R & curvæ in O, erit $\frac{1}{RO}=\frac{2}{RA}$, adeoque RA = 2RO.

§ 68. Prop. X. Recta duo puncta flexus contrarii conjungens vel tranſit per 3^um^ punctum flexus contrarii vel dirigitur in eandem plagam cum crure infinito curvæ Fig. 39.

Sint A et *a* puncta flexus contrarii, juncta A*a* curvæ occurrat in a, eritque a quoque punctum flexus contrarii. Si enim tangens figuræ in puncto a curvæ occurreret in alio quovis puncto *c*, forent A, *a*, *c*, in eadem rectâ. Verum ex hypotheſi ſunt A, *a*, et a in eadem recta, quæ igitur lineæ tertii ordinis occurreret in punctis quatuor. Sit A punctum flexus contrarii, & recta AO aſymptoto parallela curvæ occurrat in O ducatur OQ curvam contingens in O, & ſecans in Q, junctæ AQ, tranſibit per D ubi curva aſymptoton ſecat.

§ 69. Prop. XI. Ductis ex puncto flexus contrarii A tangentibus ad curvam AF, AG, AH; & duabus ſecantibus quibuſcunque ABC, A*bc*, junctæ B*b* et C*c* vel B*c* et *b*C ſe mutuo ſecabunt in recta FH quæ contactus conjungit. Fig. 38.

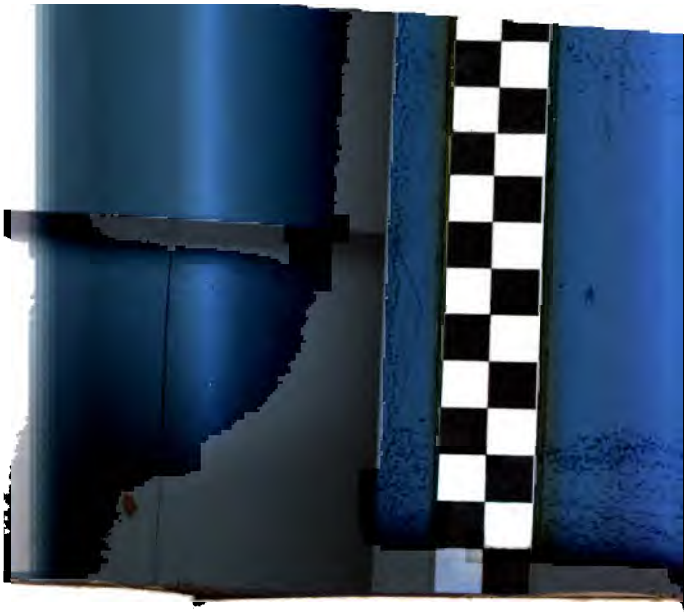
Occurrat enim recta B*b* ipſi FH in Q, et BC eidem in P; jungantur QA et QC; cumque ſit AB ad AC ut PB ad PC, per Prop. IX. erunt QA, QB, QP et QC, harmo-

harmonicales, adeoque $Ab$ secabit rectam QC in $c$ et ipsam FH in $p$, ita ut $Ab$ sit ad $Ac$ ut $pb$ ad $pc$; & proinde erit $c$ punctum curvæ, per Prop. IX. unde sequitur converse rectas $Bb$ et $Cc$ convenire in puncto Q rectæ FH; & similiter ostenditur rectas Bc et $b$C sibi mutuo occurrere in puncto $q$ ejusdem rectæ.

§ 70. *Corol.* 1. Ex puncto quovis Q rectæ FH ducantur ad curvam rectæ QB, QC, eam secantes in punctis B, $b$, M et C, $c$, N; tum junctæ CB, $cb$, MN, convenient in puncto flexus contrarii A; junctæ Bc et $b$C, Mc et N$b$, $Bb$ et C$c$, NB et MC, convenient in recta FH.

§ 71. *Corol.* 2. Tangentes ad puncta B et C convenient in puncto aliquo T rectæ FH; & si a puncto quovis T in recta FH sito ducantur tangentes ad curvam, rectæ contactus conjungentes vel transibunt per punctum flexus contrarii, vel convenient in recta FH.

§ 72. *Corol.* 3. Dato puncto flexus contrarii A, & punctis B, C, $b$, $c$, ubi duæ rectæ ex eo ductæ curvam secant, datur recta FH positione; junctæ enim $Bb$ et C$c$ occursu suo dabunt punctum Q, & junctarum Bc et $b$C occursus dabit $q$, ductaque Q$q$ ea est quæ contactus F, G, et H, conjungit. His autem quinque punctis datis cum aliis duobus M et $m$, determinatur linea tertii ordinis quæ per hæc septem puncta A, B, C, $b$, $c$, M, $m$, transit & in puncto A habet flexum contrarium. Ex punctis enim M et $m$ dantur N et $n$, ubi ductæ AM et A$m$ curvam secant, & his novem conditionibus linea determinatur. Si autem dentur tria puncta M, $m$, et S; hæc dabunt tria alia N, $n$, et $s$; unde darentur undecim conditiones ad figuram determinandam, quæ nimiæ sunt.





cales, adeoque *Ab* fecabit rectam QC ;
*f in p*, itur ut *Ab* fit ad Ac ut *pb* ad *pc*; b
punctum curvæ, per Prop. IX. unde fec
rectas *Bb* et *Cc* convenire in puncto Q
militer oftenditur rectas Bc et *bC* ita re
in puncto *q* ejufdem rectæ.

*orol.* 1. *Ex puncto quovis* Q *ducta* FH *c*
curvam rectæ QB, QC, eam fecare
*b*, *M* et *C*, *c*, *N*; tum junctæ *CB*, *cb*, *M*
*in puncto flexus contrarii A*; junctæ
*Cc*, *Bb* et *Cc*, *NB* et *MC*, conveni

2. *Tangentes ad puncta* B et C
*o aliquo T rectæ FH*; & fi puncta
*B*, *FH fito ducantur tangentes ad*
*ctus conjungentes vel transibit p*
*contrarii, vel convenient in rebus*

. *Dato puncto flexus contrarii A*
*c, ubi duæ rectæ ex eo ductæ curv*
*FH positione*; junctæ enim Bc, C
*punctum* Q, & *junctarum Bc, C*
*octaque Qq ea eft quæ contactu*
. *His autem quinque punctis data*
*et m, determinatur linea tertii or*
*eptem puncta A, B, C, b, c, M, m,*
*A habet flexum contrarium. Ex*
*dantur N et n, ubi ductæ AM et*
*& his novem conditionibus linea*
*em dentur tria puncta M, m, et S*
*I, n, et s*; unde darentur unde
*m determinandam, quæ nimir*
*fent.*

*Proprietatibus generalibus.* 413

funt. Similiter dato puncto flexus contrarii A cum punctis F, G, (adeoque tangentibus AF et AG) et punctis M et *m* quibufcunque, datur recta FG, adeoque puncta N et *n*, et determinatur curva.

§ 73. *Corol* 4. Contingant rectæ HB, HC, curvam in B et C, et juncta CB tranfibit per A, junctæ CG et FB concurrent in puncto curvæ V, et ducta VH curvam continget in V. Tangens autem ad punctum flexus contrarii A determinatur ducendo AN cui occurrat in L, recta PL ipfi AH parallela & bifecanda PL in X ; juncta enim AX erit tangens ad punctum A. Occurrat enim tangens ad A rectæ FH in S ; eritque $\frac{1}{PS} + \frac{2}{PH} = \frac{1}{PH} + \frac{1}{PG} - \frac{1}{PF}$, adeoque $\frac{1}{PS} + \frac{1}{PH} = \frac{1}{PG} - \frac{1}{PF}$ (quoniam AC fecantur harmonice in P et B, adeoque VA, VF, VP, et VG, harmonicales) $= \frac{2}{PK}$. Eft igitur PK medium harmonicum inter PS et PH ; unde fi PL parallela rectæ AH occurrat rectis AV et AS in X et L, erit PX = XL. Fig. 40.

§ 74. PROP. XII. Ex puncto lineæ tertii ordinis A ducantur duæ rectæ curvam contingentes in F et G, junctæ FG curvæ occurrat in H, & tangens ad punctum A fecet curvam in M ; jungatur HM, cui occurrat FLK ipfi AH parallela in L, & fumatur FK = 2FL ; tum junctæ HK, recta quævis AB ex A ducta harmonice fecabitur a rectis HK et HF in N, P, et a curva in B, C ; ita ut NB erit ad NC ut BP and PC. Fig. 41.

Occurrat

Occurrat enim recta AB tangenti HM in T, eritque $\frac{1}{PB} + \frac{1}{PA} - \frac{1}{PC} = \frac{2}{PA} + \frac{1}{PT}$, adeoque $\frac{1}{PB} - \frac{1}{PC} = \frac{1}{PA} + \frac{1}{PT}$ (per conſtructionem, & *harmonica*) $= \frac{2}{PN}$. Unde ſequitur rectam NC ſecari harmonice in punctis B et P, vel NB eſſe ad NC ut BP ad PC.

§ 75. *Corol.* 1. Hinc ſi duæ quævis rectæ ex A ductæ ſecentur in N harmonice ita ut PC ſit ad PB ut CN ad BN, omnes rectæ ex A eductæ a rectis HF et HK ſimiliter harmonice ſecabuntur.

§ 76. *Corol.* 2. Si curva punctum duplex non habeat, eamque ſecet recta HK in duobus punctis *f* et *g*, ductæ *Af* et *Ag* erunt rectæ curvam contingentes in his punctis. Coincidat enim punctum B cum puncto N, quando N pervenit ad *f* occurſum rectæ HK cum curva; adeoque cum $\frac{1}{PB} + \frac{1}{PC} = \frac{1}{PN}$, erit $\frac{1}{PC} = \frac{1}{PN}$, et coincidit C cum B, et recta ex A ducta curvam tunc contingit. Ex altera parte, ſi recta *Af* curvam contingat tranſibit recta HK per *f*; ob æquales enim PB, PC, in hoc caſu, coincidunt puncta B et C cum N.

§ 77. *Corol.* 3. Si recta HK in ſolo puncto H curvæ occurrat, duæ tantum tangentes duci poterunt a puncto A ad curvam, viz. AF et AG. Quatuor tantum ad ſummum tangentes duci poſſunt a puncto quovis lineæ tertii ordinis ad curvam ut AF, AG, *Af*, Ag. Si enim alia quavis tangens duci poſſet a puncto A ad curvam ut Aφ, recta HK tranſiret per punctum φ, et quatuor puncta

puncta lineæ tertii ordinis forent in eadem recta, viz. H, *f*, *g*, *φ*. *Q. E. A.*

§ 78. PROP. XIII. Si ex puncto lineæ tertii ordinis duci possunt quatuor rectæ curvam contingentes, rectæ contactus conjungentes conveniunt semper in puncto aliquo curvæ, & recta quævis a primo puncto ducta harmonice secabitur a curva & rectis binos contactus conjungentibus:

Sit A punctum curvæ, AF, AG, A*f*, et A*g*, rectæ curvam contingentes in punctis F, G, *f*, et *g*. Jungantur FG et *fg*, quibus occurrat recta quævis ABC (ex A ducta curvamque secans in B et C) in P et N; & recta NC harmonice secabitur in B et P, ita ut semper sit NC ad NB ut CP ad PB: sequitur ex Corol. 2. præcedentis. Rectæ autem FG et *fg* concurrunt in puncto curvæ H; & similiter rectæ F*f* et G*g* conveniunt in E, atque F*g* et G*f* in R; et E, R erunt puncta curvæ, per idem corollarium. Atque hinc est posterior duarum proprietatum linearum tertii ordinis quas descripsimus in tractatu de fluxionibus, Art. 402. Quod si recta AM curvam contingat in A, et secet in M, junctæ ME, MR, MH, curvam tangent in punctis E, R, H; & rectarum AE et HR, AR et HE, AH et RE occursus erunt quoque in curva.

§ 79. *Corol.* Cum igitur sint rectæ HK, HB, HP, et HC, harmonicales; si rectæ HB ob HC curvæ occurrant in *b* et *c*; erunt puncta A, *b*, *c*, in eadem recta linea. Occurrat enim junctæ A*b* curvæ in *b* et *c* at-

* Supple quæ desunt in Schemate.

que

que ipſi HF in $p$, et HK in $n$; cumque ſit $nc$ ad $nb$ ut $pc$ ad $pb$ patet $c$ eſſe in recta HC; & reciproce ſi $c$ ſit in recta HC et $b$ in recta HB, erunt A, $b$, $c$, in eadem rectâ.

Fig. 42. § 80. PROP. XIV. Habeat linea tertii ordinis punctum duplex O. Ex puncto quovis curvæ A ducantur duæ rectæ AF et AG curvam contingentes in F et G; ducta FG curvam ſecet in H; jungatur OH. Recta quævis AB ex A ducta curvæ occurrat in punctis B et C, rectæ FG in P, & rectæ OH in N; & recta NP harmonice ſecabitur in punctis B et C, ita ut PB ſit ad PC ut BN ad NC.

Jungatur enim AO quæ rectæ FG occurrat in $p$ et tangenti HL in $t$; cumque ſit O punctum duplex, erit $\frac{2}{pO}+\frac{1}{pA}=\frac{1}{pA}+\frac{1}{pt}$, adeoque $\frac{1}{pA}+\frac{1}{pt}=\frac{2}{pO}$. Secatur igitur $pA$ harmonice in $t$ et O, ita ut $pt$ ſit ad $pA$ ut $tO$ ad OA, et harmonicales ſunt H$p$, H$t$, HO, et HA. Occurrat recta PA tangenti LH in T, cumque ſit $\frac{1}{PC}+\frac{1}{PB}+\frac{1}{PA}=\frac{2}{PA}+\frac{1}{PT}$, erit $\frac{1}{PC}+\frac{1}{PB}=\frac{1}{PA}+\frac{1}{PT}=\frac{2}{PN}$; conſequenter PC eſt ad NC ut PB ad BN.

§ 81. *Corol.* Si tangens HL occurrat rectæ GZ ipſi AH parallelæ in Z, & ſumatur GV=2GZ, ducta HV tranſibit per punctum duplex O, ſi modo curva tale punctum habeat. Vel ſi recta G$ra$ occurrat rectis AH et HR in $a$ et $r$, junctæ $r$A et R$a$, ſe decuſſent in $m$, junctæ H$m$ tranſibit per punctum duplex O.

§ 82.

ipſi HF in $p$, et HK in $\pi$; cumque ſit $\pi$ :
d $p\delta$ patet $c$ eſſe in rectâ HC; & recipr
i rectâ HC et $b$ in rectâ HB, erunt $A$, $\delta$, ...
rectâ.

80. Prop. XIV. Habeat linea tertii
ctum duplex O. Ex puncto quov
A ducantur duæ rectæ AF et AG c
ingentes in F et G; ducta FG curva
; jungatur OH. Recta quæris ub
curvæ occurrat in punctis B et C
P, & rectæ OH in N; & rectis NP
ce ſecabitur in punctis B et C, ita ut
ut BN ad NC.

atur enim AO quæ rectæ FG occurrat
HL in $t$; cumque ſit O punctum
$\frac{1}{A} = \frac{1}{pA} + \frac{1}{pt}$, adeoque $\frac{1}{pA} + \frac{1}{p\pi} = \frac{1}{p\delta}$;
tur $pA$ harmonice in $t$ et O, ita ut $p\pi$ ...
OA, et harmonicales ſunt $H\rho$, $H\delta$, ...
ccurrat recta PA tangenti LH in T, cui
$\frac{1}{PB} + \frac{1}{PA} = \frac{2}{PA} + \frac{1}{PT}$, erit $\frac{1}{PC} + \frac{1}{PB}$ ...
$= \frac{2}{PN}$; conſequenter PC eſt ad NC ...

ol. Si tangens HL occurrat rectæ GZ ...
e in Z, & ſumatur GV = GZ, ducta ...
punctum duplex O, ſi modo curva ...
ocat. Vel ſi recta $Gr\sigma$ occurrat rectis AF ...
t $r$, junctæ $rA$ et $R\sigma$, ſe decuſſent in ...
anſibit per punctum duplex O.



§ 82. Prop. XV. Ex puncto lineæ tertii ordinis ducantur duæ tangentes, & ex alio quovis ejuſdem puncto ducantur rectæ ad contactus curvam in duobus aliis punctis ſecantes; tangentes ad hæc duo nova puncta in eodem puncto curvæ convenient.

Ex puncto A ducantur rectæ AF et AG curvam contingentes in F et G. Sumatur punctum quodvis curvæ P, jungantur PF et PG curvam ſecantes in punctis K et L; atque tangentes ad puncta K et L concurrent in puncto aliquo curvæ B. Determinatur autem punctum B, ducendo rectam PC quæ curvam contingit in P, et ſecat in C; ſi enim jungatur AC, occurret denuo curvæ in puncto B. Fig. 45.

Cum enim puncta F, K, P, ſint in eadem rectâ, & tangentes ad puncta F et P curvam ſecent in A et C; ſequitur tangentem ad punctum K tranſituram per B. Et ob rectam LGP, tangens ad punctum L tranſibit quoque per B.

§ 83. *Corol.* Sint igitur A et B duo quævis puncta in linea tertii ordinis; ex utroque ducantur quatuor rectæ curvam in aliis quatuor punctis contingentes, viz. AF, AG, $A\phi$, $A\gamma$; et BK, BL, $B\kappa$, $B\lambda$; junctæ FK et GL, FL et GK, F$\lambda$ et G$\kappa$, G$\lambda$ et F$\kappa$; ſibi mutuo occurrent in quatuor punctis curvæ, P, Q, $q$, $p$; & ſi ducantur tangentes ad hæc quatuor puncta, hæ occurrent curvæ & ſibi mutuo in puncto C ubi recta AB curvam ſecat. Unde ſi ſint tria puncta lineæ tertii ordinis in eadem rectâ, & ex ſingulis ducantur quatuor rectæ curvam contingentes in quatuor aliis punctis, recta per duo quævis puncta contactus ducta curvam ſemper ſecabit in alio aliquo Fig. 46.

alio puncto contactus; & quatuor hujuſmodi rectæ per idem punctum contactus ſemper tranſibunt.

Fig. 43. § 84. PROP. XVI. Sint F et G puncta duo lineæ tertii ordinis, ita ſumpta ut rectæ FA et GA curvam in his punctis contingentes conveniant in puncto aliquo curvæ A. Sumatur in curva aliud quodvis punctum P, unde ducantur ad puncta F et G rectæ PF et PG quæ curvæ occurrunt in K et L; jungantur FL et GK, atque harum occurſus Q erit in curva. Tangentes autem ad puncta K et L ſibi mutuo & curvæ occurrent in puncto aliquo curvæ B, atque tangentes ad puncta P et Q convenient in puncto curvæ C, ita ut tria puncta A, B, C, ſint in eadem recta.

Ducatur enim tangens ad punctum P quæ curvæ occurrat in C, & ducta AC ſecet eandem in B; & ductæ BK, BL, erunt tangentes ad puncta K et L, per præcedentem. Occurrant recta LF curvæ in Q; & ſi recta GK non tranſeat per Q, occurrat curvæ in $q$. Quoniam igitur tria puncta L, F, Q, ſunt in eadem recta, tangentes vero ad L et F curvam ſecent in B et A, ſequitur (per Prop. VII.) tangentum ad punctum Q tranſire per punctum C. Similiter, cum ſint puncta G, K, et $q$, in eadem recta, tangentes autem ad puncta G & K tranſeant per A et B, tangens ad punctum $q$ tranſibit quoque per punctum C. Utraque igitur recta CQ, C$q$, curvam contingit prior in Q, poſterior in $q$. Coincidunt igitur puncta Q et $q$, ſi enim diverſa eſſe ponamus, ſequitur per Prop. VIII. plures quam quatuor tangentes duci poſſe ad curvam ex eodem puncto C. Sint enim

Aſ

unctо contactus; & quatuor hujuſmodi
m punctum contactus ſemper tranſibunt.

4. PROP. XVI. Sint F et G punct
tertii ordinis, ita ſumpta ut recta FG
urvam in his punctis contingentes ne
in puncto aliquo curvæ A. Sumat
aliud quodvis punctum P, unde ducat
ncta F et G rectæ PF et PG quæ curv
unt in K et L; jungantur FL et G
harum occurſus Q erit in curva. Ta
autem ad puncta K et L ſibi mutu
occurrent in puncto aliquo curvæ A
gentes ad puncta P et Q convenie
curvæ C, ita ut tria puncta A, B, C
n recta.

ur enim tangens ad punctum P quæ curvæ
C, & ducta AC fecet eandem in B, & ita
erunt tangentes ad puncta K et L, quæ
Occurrant recta LF curvæ in Q, & ita
anſeat per Q, occurrat curvæ in p. Q
tria puncta L, F, Q, ſunt in eadem re
ero ad L et F curvam fecerit in B et A;
Prop. VII.) tangentum ad puncta Q, p
ctum C. Similiter, cum ſint puncta G, E
n recta, tangentes autem ad puncta G & E
A et B, tangens ad punctum q tranſibit qu
ctum C. Utraque igitur recta OQ, G
ngit prior in Q, poſterior in q. Coincidat
Q et q, ſi enim diverſa eſſe ponantur, e
rop. VIII. plures quam quatuor tangen
curvam ex eodem puncto C. Sint tam
A

A*f* et A*g* rectæ quæ curvam contingant in *f* & *g*, & ductæ L*f*, L*g*, curvam ſecent in *m* & *n*; & rectæ C*m*, C*n*, erunt tangentes ad puncta *m* et *n*. Quare haberemus quinque tangentes ex C ad curvam ductas CP, CQ, C*m*, C*n*, & C*q*; quod repugnat Corol. 3. Prop. XII.

§ 85. *Corol.* 1. Dato puncto P, ubicunque ſumantur puncta F & G, modo tangentes ad hæc puncta in curva conveniant, datur punctum Q, ubi junctæ FL & GK occurrunt ſibi mutuo & curvæ. Et ſi a puncto P ducatur recta quævis PNM quæ curvæ occurrat in N et M, & junctæ QM, QN, eam ſecent in *m* & *n*; erunt puncta P, *n*, & *m*, in eadem recta linea. Oſtendimus enim tangentes ad puncta P & Q, ſe mutuo decuſſare in puncto curvæ *.

§ 86. *Corol.* 2. Si ſumantur quatuor puncta F, G, K, L, in linea tertii ordinis, ita ut tangentes ad puncta F & G, conveniant in aliquo puncto curvæ, & tangentes ad puncta K et L, conveniant quoque in aliquo puncto curvæ, ductæ FK & GL concurrent in puncto curvæ, & ductæ FL & GK ſibi mutuo occurrent in puncto curvæ. Fig. 43.

§ 87. Prop. XVII. Sint F et G duo quævis puncta lineæ tertii ordinis, ubi ſi rectæ ducantur curvam contingentes, hæ ſe mutuo ſecabunt in puncto aliquo curvæ. Sumantur alia quatuor puncta curvæ L, K, *f*, *g*, ita ut ductæ LF et GK conveniant in curva, atque rectæ F*f* et G*g*, in eâ quoque conveniant; tunc ductæ L*f* et *g*K, ſe mutuo ſecabunt in curva, ut & ductæ L*g* et K*f*.

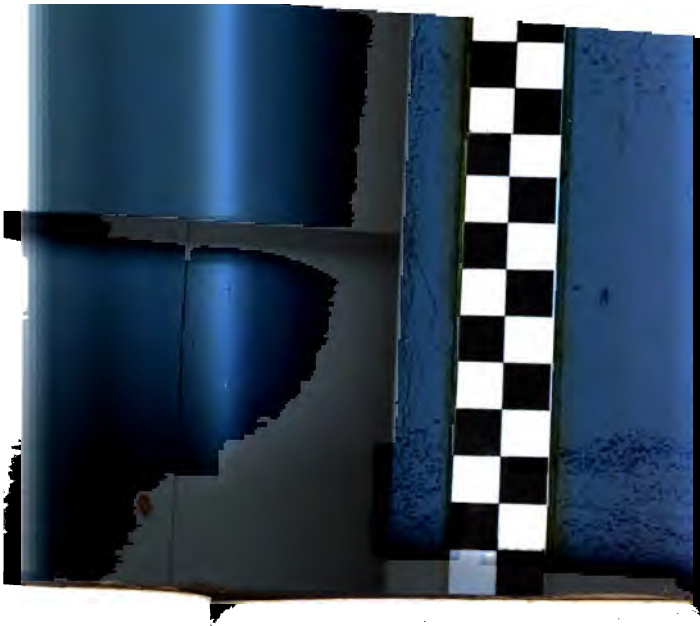
* Supple quod deeſt in Schemate.

Tangentes enim adpunctia *f*, et *g* se mutuo decussant in curva, per Prop. XVI., ut & tangentes ad puncta K et L, per eandem. Adeoque per Corol. 2. praecedentis, junctæ *f*L et K*g* conveniunt in curva, ut et *f*K et *g*L.

Fig. 45. n. 1. § 88. *Lemma.* Dentur tres rectæ IC, IH, et CH, positione; & tria puncta P, G, δ, quæ sint in eadem recta linea. Sumatur punctum quodvis Q in recta IC, junctæ QF occurrat rectæ IH in *L*, & junctæ QG rectæ HC in P; jungatur FP, ducta Sδ occurrat rectis FP et QP in *k* et N; atque puncta *k* et N erunt ad rectas positione datas. Jungatur enim IN, quæ occurrat rectæ GS in *m*, & ducatur per N parallela rectæ FS quæ occurrat rectis IC, IH, et LQ, in punctis *x*, *u*, et *r*; occurrat recta FG rectis IC, IH, et HC, in *a*, *b*, et *l*. Quoniam N*x* est ad N*r* ut G*a* ad GF, et N*r* ad N*u* ut SF ad S*b*, erit N*x* ad N*u* (adeoque *ma* ad *mb*) ut G*a* × SF ad GF × S*b*, i. e. in data ratione. Datur igitur punctum *m*, adeoque recta IN, positione; & similiter est punctum *k* ad positione datum.

n. 2. § 89. *Corol.* Coincidentibus punctis S et G, coincidit quoque punctum *m* cum puncto G. Jungatur igitur IG quæ rectæ HC occurrat in D, & ducta CF occurrat rectæ HI in E, tum junctæ DE, dabit locus puncti K ubi ductæ GL et FP se mutuo decussant.

Fig. 46. § 90. PROP. XVIII. Sit PGLFQK quadrilaterum inscriptum figuræ, cujus sex anguli tangant lineam tertii ordinis ut in Prop. XVI. Ducantur rectæ curvam contingentes IC, CH, HI, in tribus punctis Q, P, L, quæ non sint in eadem rectâ; jungatur IG quæ tangenti CH occurrat





occurrat in D, et HF quæ tangenti CI occurrat in E; erunt puncta D, K, E, in eadem recta linea, quæ quidem curvam in puncto K contingit.

Supponamus enim rectas QFL et FKP moveri circa polum F, & rectas LGP et QKG circa polum G, puncta autem Q, L, et P, deferri in tangentibus QI, LI et PC; tum punctum K movebitur in recta DE, per Corol. præcedens. Unde si puncta Q, L, P, ferantur in curva quæ has rectas QI, LI, et PC, in his punctis contingit, movebitur quoque in curva quam recta DE contingit. Sed per Prop. XV, si puncta Q, L, P, ferantur in linea tertii ordinis proposita, punctum K movebitur in eadem, quam igitur recta DE contingit in K.

§ 91. *Corol.* 1. Similiter si rectæ AF et AG (quæ curvam contingunt in F et G) occurrant rectæ IH (quæ curvam contingit in L) in punctis M et N; juncta MP secet tangentem AG in *d*, & juncta QN tangentem AF in *e*; recta *de* transibit per K, & curvam in hoc puncto continget; atque quatuor puncta D, *d*, *e*, E, erunt in eadem rectâ linea.

§ 92. *Corol.* 2. Ex duabus punctis curvæ quibuscunque C et B ducuntur ad curvam quatuor contingentes binæ ex singulis, CQ et CP ex puncto C, BL et BK ex puncto B, sintque harum tangentium occursus I, H, E, et D; tum ductæ LQ et EH se mutuo secabunt in puncto curvæ F; atque junctarum LP et ID occursus erit in puncto curvæ G; tangentes autem ad puncta F et G se mutuo secabunt in puncto curvæ A quod est in eadem recta cum punctis C et B.

§ 93. *Corol.* 3 Datis tribus punctis lineæ tertii ordinis quæ sint in eadem rectâ, & duabus tangentibus ex

horum ſingulis ductis ad curvam poſitione datis, ſex puncta contactus determinantur per hanc propoſitionem. Sint A, B, C, tria curvæ puncta data in eadem rectâ, AM et AN tangentes ex A, BM*l*, et BD*E*, tangentes ex B quæ prioribus occurrant in M, N, *e*, et *d*; ſintque CD et C*E* tangentes ex tertio puncto C ductæ; atque occurrat CD ipſis BM, BD, AM, et AN, in H, D, *b*, et *c*, & C*E* iiſdem in I, E, *n* et *m*. His poſitis, juncta N*e* ſecabit tangentem C*I* in puncto contactus Q, M*d* ſecabit tangentem CD in puncto contactus P, I*D* ſecabit tangentem AN in puncto contactus G, E*H* tangentem AM in contactu F, *mb* ſecabit tangentem BH in L, & denique *nc* tangentem B*E* in K. Quamvis autem problema in hoc caſu determinatum ſit, ſolutiones tamen plures admittit. Diverſæ enim lineæ tertii ordinis, ſed numero definitæ, per tria puncta A, B, et C, duci poſſunt contingentes ſex rectas poſitione datas AM, AN, BM, BD, CD, et C*E*. Occurrat enim N*e* tangenti CD in *p*, recta M*d* tangenti C*E* in *q*, I*D* tangenti AM in *f*, E*H* tangenti AN in *g*, *nc* tangenti BM in *l*, et *mb* tangenti BD in *k*; atque linea tertii ordinis quæ conditionibus propoſitis ſatisfacit continget rectas CD et C*E* vel in P et Q, vel in *p* et *q*. Ea continget rectas AM et AN vel in punctis F et G vel in *f* et *g*; rectas autem BM et BD vel in L et K, vel in *l* et *k*. Conſtat igitur plures lineas tertii ordinis problematis conditionibus ſatisfacere poſſe, ſed numero determinatas, adeoque problema eſſe determinatum *.

§ 94. *Corol.* 4. Datis duobus punctis lineæ tertii ordinis A et B, tangentibus quoque AM, AN, BM, BD poſitione datis cum tribus punctis contactus F, G, et L, datur punctum K ubi recta BD curvam contingit.

* Supple quæ deſunt in Schemate.

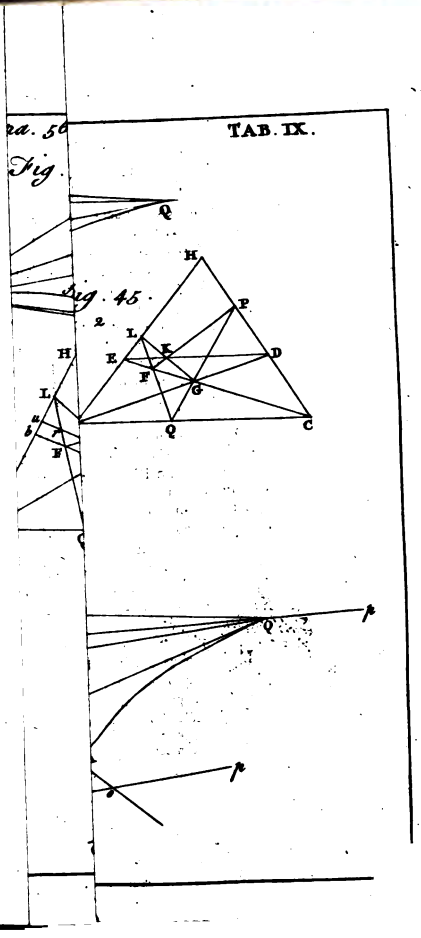
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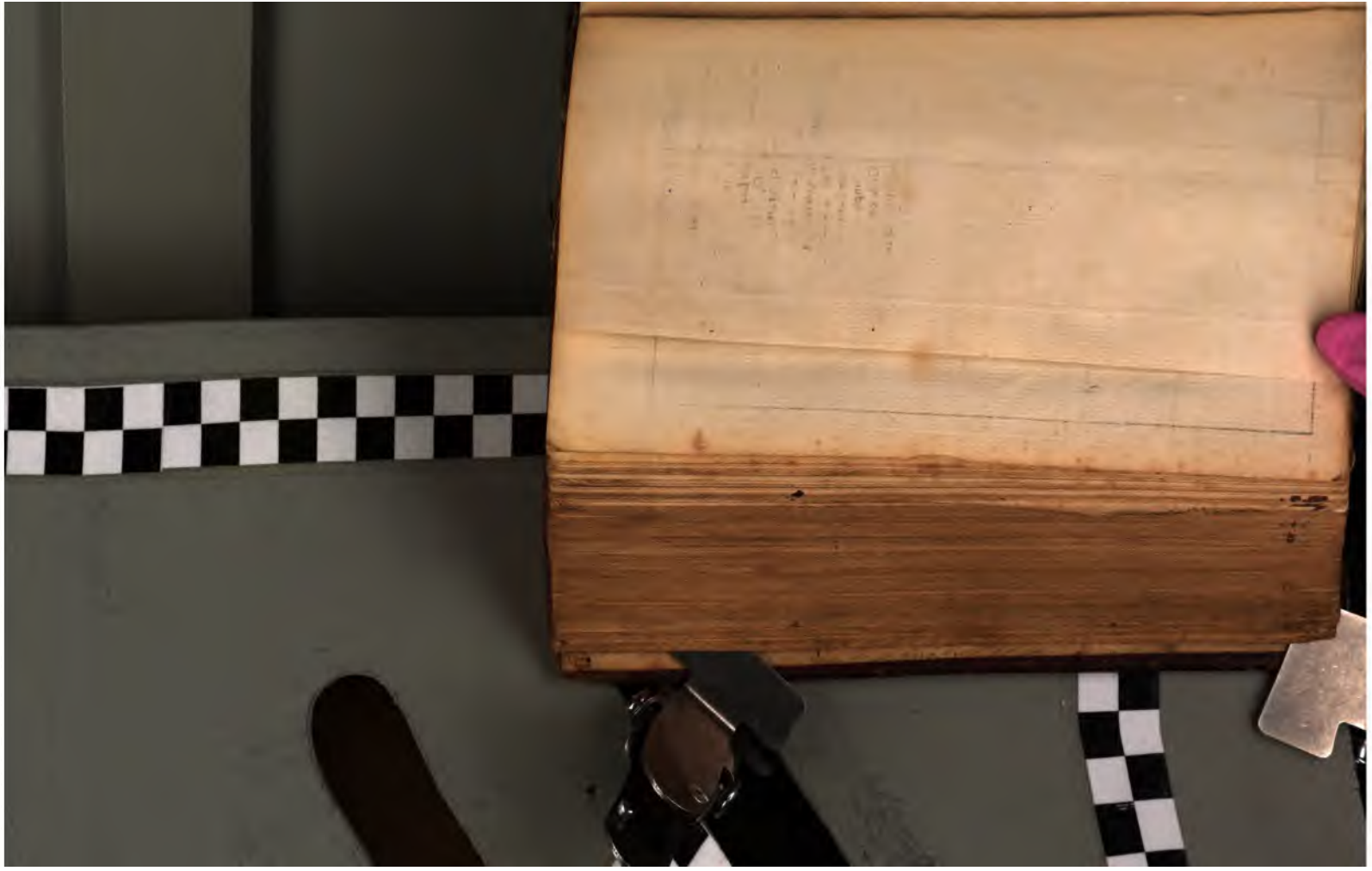
ngulis ductis ad curvam positione data, e
ntactus determinantur per hanc propositi
, C, tria curvæ puncta data in eadem recta
igentes ex A, BM, et BDE, tangenti
ibus occurrant in M, N, ν, et ν; itemq
ngentes ex tertio puncto C ductæ; quæ
ipsis BM, BD, AM, et AN, in H, D,
nsdem in I, E, π et m. His positis, jungi
gentem CI in puncto contactus Q, MN
CD in puncto contactus P, ID secabit
N in puncto contactus G, EH tangentem
F, mb secabit tangentem BH in L, &
gentem BE in K. Quamvis autem prius
determinatum sit, solutiones casus pr
Datæ enim lineæ tertii ordinis, tr
tas, per tria puncta A, B, et C, duc
s sex rectas positione datas AM, AN,
t CE. Occurrat enim Ne tangenti C
tangenti CE in q, ID tangenti AM in
AN in g. nc tangenti BM in l, et ma
k; atque linea tertii ordinis quæ conta
ctis satisfacit continget rectas CD et CI
cl in p et q. Ea continget rectas AM e
nctis F et G vel in f et g; rectæ mm
in L et K, vel in l et k. Constat qua
rtii ordinis problematis conditionibus
sed numero determinatas, adeoque po
minatum *.

4. Datis duobus punctis linea ter
tangentibus quoque AM, AN, BM,
tis cum tribus punctis contactus F, G,
dum K ubi recta BD curvam contingi

ple quæ desunt in Schemate.

Sc





Si enim ducantur rectæ N*e* et LF, harum occurſu dabitur punctum Q, & ducta QG ſecabit contingentem BD in puncto contactus K. Datur quoque punctum P occurſus rectarum LG et M*d*, vel rectarum M*d* et FK; tres enim rectæ LG, M*d*, et FK, neceſſario conveniunt in puncto P. Sit M*ed*N quadrilaterum quodvis, ſumatur punctum quodvis Q in diagonali N*e* et P in diagonali M*d*, recta quævis QFL ex Q ducta ſecet latera M*e* et MN in F et L, ducta PL ſecet latus N*d* in G, jungatur QG quæ latus *de* ſecet in K; atque puncta F, K, P, erunt ſemper in eadem recta linea, per ſuperius oſtenſa. Unde conſtat problema non ideo fieri impoſſibile, quod oporteat tres rectas LG, M*d*, et FK, in eodem puncto convenire.

§ 95. PROP. XIX. Sint D, E, F, puncta linæ tertii ordinis in eadem recta, ſintque tres rectæ curvam in his punctis contingentes ſibi mutuo parallelæ. In recta DF ſumatur punctum P ita ut 2PF ſit medium harmonicum inter PD et PE; & ſi alia quævis recta per P ducta curvæ occurrat in *f*, *d*, et *e*, erit ſemper 2P*f* medium harmonicum inter P*d* et P*e*. Supponimus autem puncta *d* et *e* eſſe ad eaſdem partes puncti P, punctum autem *f* eſſe ad contrarias. Fig. 47.

Occurrant enim tangentes DK, EL, FM, rectæ *df* in punctis K, L, et M; eritque per Art. 9. $\frac{1}{Pf} - \frac{1}{Pd} - \frac{1}{Pe} = \frac{1}{PM} - \frac{1}{PK} - \frac{1}{PL}$ (ſi recta Q*q* tangentibus parallela harmonice ſecet rectam PD ita ut PE ſit ad EQ ut PD ad DQ, et Q*q* occurrat rectæ *fd* in

in $q$) $= \frac{1}{PM} - \frac{2}{Pq}$ (quoniam $Pq$ eſt ad PM ut PQ ad PF, & ex hypotheſi $2PF = PQ$, adeoque $2PM = Pq$) $= \frac{1}{PM} - \frac{1}{PM} = 0$; unde $\frac{1}{Pf} = \frac{1}{Pd} + \frac{1}{Pe}$, adeoque $2Pf$ eſt medium harmonicum inter $Pd$ et $Pe$.

§ 96. *Corol.* 1. Jungantur $Dd$ et $Ee$ quæ conveniant in puncto V, junctæ VQ et $Ff$ erunt parallelæ; & producta VQ donec occurrat rectæ $fd$ in $r$, erit $Pf = \frac{1}{2}Pr$. Recta enim PD ſecatur harmonice in E et Q, ex hypotheſi, adeoque etiam recta $Pd$ ſecatur harmonice in $e$ et $r$, per Art. 21. unde $Pf = \frac{1}{2}Pr$; cumque ſit $PE = \frac{1}{2}PQ$; ſequitur rectam $Ff$ parallelam eſſe harmonicali $VQr$.

§ 97. *Corol.* 2. Similiter ſi ſumatur in recta DF punctum $p$ ita ut $2pD$ ſit æqualis medio harmonico inter $pE$ et $pF$, & recta quævis ex $p$ ducta curvæ occurrat in tribus punctis, erit ſegmentum hujus rectæ ex una parte puncti $p$ ad curvam terminatum æquale dimidio medii harmonici inter duo ſegmenta eodem puncto $p$ et curvâ ad alteras partes terminata.

Fig. 48. § 98. *Lemma.* Ex centro gravitatis trianguli ducatur recta quævis quæ tribus lateribus trianguli occurrat, & ſegmentum hujus rectæ centro gravitatis & uno trianguli latere terminatum erit dimidium medii harmonici inter ſegmenta ejuſdem rectæ centro gravitatis & duobus aliis trianguli lateribus terminata. Sit P centrum gravitatis trianguli VTZ, occurrat recta FDE per P ducta lateribus in F, D, E; ſintque puncta D et E ad eaſdem partes puncti P; eritque $\frac{1}{PF} = \frac{1}{PD} + \frac{1}{PE}$. Ducatur enim per punctum P, recta MPL lateri VZ parallela, quæ

$\frac{1}{PM} - \frac{2}{Pf}$ (quoniam $Pf$ eſt ad $PM$ ut $PQ$ hypotheſi $2PF = PQ$, adeoque $2PM - Pf = 0$; unde $\frac{1}{Pf} = \frac{1}{PF} + \frac{1}{PF}$, hinc dium harmonicum inter $Pa$ et $Pe$.

Corol. 1. Jungantur $Dd$ et $Ee$ quæ curvæ V, junctæ $VQ$ et $Ff$ erunt parallelæ Q donec occurrat rectæ $fd$ in $r$, et ſi recta enim $PD$ ſecatur harmonice in $e$ i, adeoque etiam recta $Pd$ ſecatur harmonice per Art. 21. unde $Pf = \frac{1}{2}Pr$; quare ; ſequitur rectam $Ff$ parallelam eſſe Qr.

2. Similiter ſi ſumatur in recta $Dd$ $pD$ ſit æqualis medio harmonico re recta quævis ex $p$ ducta curvæ occur , erit ſegmentum hujus rectæ ex una pa arvam terminatum æquale dimidio re r duo ſegmenta eodem puncto p ter s terminata.

. Ex centro gravitatis trianguli ducta æ tribus lateribus trianguli occurat, i is rectæ centro gravitatis & unotriangu m erit dimidium medii harmonici inter n rectæ centro gravitatis & duobus lat is terminata. Sit $P$ centrum gravitat occurrat recta $FDE$ per $P$ ducta late ; ſintque puncta $D$ et $E$ ad eaſdem eritque $\frac{1}{PF} = \frac{1}{PD} + \frac{1}{PE}$. Ducat n $P$, recta $MPL$ lateri $VZ$ parallela, quæ lateribus $VT$, $ZT$, occurrat in $L$ et $M$ et rectæ $VN$ parallelæ lateri $ZT$ in $N$; cumque ſit $MP = PL$, et $TL = 2VL$, ob ſimilia triangula $TLM$, $VLN$, erit $LM = 2LN$, unde $LN = LP$, et $PN = 2PM$, proinde ſi $PD$ occurrat rectæ $VN$ in $K$, erit (per Art. 21. & 23.) $\frac{1}{PD} + \frac{1}{PE} = \frac{2}{PK} = \frac{1}{PF}$.

§ 99. Prop. XX. Contingant tres rectæ $VT$, $VZ$, $TZ$, lineam tertii ordinis tranſeatque eadem recta linea per tres contactus & per $P$ centrum gravitatis trianguli $VTZ$; recta quævis per hoc centrum ducta curvæ occurrat in puncto $e$ ex una parte & in punctis $a$ et $b$ ex altera ejuſdem centri gravitatis parte, eritque $2Pe$ medium harmonicum inter ſegmenta $Pa$ et $Pb$. Fig. 49.

Occurrat enim recta $Pe$ lateribus trianguli $VTZ$ in $f$, $d$, et $e$; & rectæ $VN$ lateri $TZ$ parallelæ in $k$; eritque $2Pf = Pk$, adeoque $\frac{1}{Pf} = \frac{2}{Pk} = \frac{1}{Pd} + \frac{1}{Pe} = \frac{1}{Pa} + \frac{1}{Pb} - \frac{1}{Pc} + \frac{1}{Pf}$, adeoque $\frac{1}{Pc} = \frac{1}{Pa} + \frac{1}{Pb}$, unde $Pc$ eſt dimidium medii harmonici inter rectas $Pa$ et $Pb$.

§ 100. Prop. XXI. Sit $V$ punctum duplex in linea tertii ordinis, $VT$ et $VZ$ rectæ curvam in hoc puncto contingentes, quibus in $T$ et $Z$ occurrat recta $TZ$ curvam contingens in $F$ ita ut $FT = FZ$; jungatur $FV$, in qua ſumatur $FP = \frac{1}{3}FV$; & ſi recta quævis per $P$ ducta curvæ occurrat in tribus punctis $a$, $b$, $c$, quorum $a$ et $b$ ſint ad eaſdem partes puncti $P$, $c$ ad partes contrarias, Fig. 50.

trarias, erit ſemper $2Pc$ medium harmonicum inter ſegmenta $Pa$ et $Pb$, ſeu $\frac{1}{Pc} = \frac{1}{Pa} + \frac{1}{Pb}$.

Cum enim biſecetur $TZ$ in $F$, ſitque $FP = \frac{1}{3}FV$, manifeſtum eſt punctum $P$ eſſe centrum gravitatis trianguli $VTZ$; cumque ſit punctum $P$ in rectâ $FV$ quæ per contactus tranſit, ſequitur propoſitio ex præcedente.

§ 101. *Corol.* 1. Si jungatur rectæ $Va$, $Vb$, et $Fc$, erit $P$ quoque centrum gravitatis trianguli hiſce rectis contenti, ut et trianguli tribus rectis curvam in $a$, $b$, $c$, contingentibus comprehenſi; & ſi ductæ $Va$ et $Vb$ occurrant rectæ $Fc$ in $m$ et $n$, erit ſemper $Fm$ æqualis $Fn$.

§ 102. *Corol.* 2. Recta per punctum duplex ducta parallela rectæ $Fc$ harmonice ſecabit ipſam $Pa$ in $k$ ita ut $Pa$ erit ad $ak$ ut $Pb$ ad $Pk$; quæ vero ducitur a puncto $k$ ad $x$ occurſum rectarum curvam in $a$ et $b$ contingentium parallela eſt recta $cy$ figuram contingenti in $c$.

§ 103. *Corol.* 3. Datis duobus punctis $a$ et $c$ ubi recta quævis ex $P$ ducta curvæ occurrit, datur tertium $b$; jungantur enim $Va$ et $Fc$ quæ ſibi mutuo occurrant in $m$; ſumatur $Fn$ ex altera parte puncti $F$ æqualis ipſi $Fm$, et juncta $Vn$ ſecabit rectam $Pa$ in $b$.

Fig. 51. § 104. PROP. XXII. Ducatur per punctum quodvis $P$ recta quæ dirigatur in plagam crurum infinitorum & occurrat curvæ in punctis $a$ et $c$; ducatur per idem punctum recta quævis curvam ſecans in punctis $D$, $E$, $F$, quæque rectis curvam in $a$ et $c$ contingentibus occurrat in $k$ et $m$, atque

aſymptoto

s, erit semper 2Pc. medium harmonic

segmenta Pa et Pl, seu $\frac{1}{Pc} = \frac{1}{Pa} +$

enim bisecetur TZ in F, sitque FP

ſtum eſt punctum P eſſe centrum gravit

VTZ; eumque ſit punctum P in rec

r contactus tranſit, ſequitur propoſitio a p

*Corol.* 1. Si jungatur rectæ Va, Vl, et

oque centrum gravitatis trianguli hinc ex

ut et trianguli tribus rectis curvam a

gentibus compræhenſi; & ſi ductæ vel b

rectæ Fc in m et n, erit ſemper Fa æqu

*Corol.* 2. Recta per punctum duplo hi

ctæ Fc harmonice ſecabit ipſam Pa in

l ak ut Pk ad Pl; quæ vero ducitur p

occurſum rectarum curvam in a et c

rallela eſt rectæ q ſigurant contingen

*ol.* 3. Datis duobus punctis a et c in

luctæ curvæ occurrit, datur tertium p

'a et Fc quæ ſibi mutuo occurrunt in

altera parte puncti F æqualis ipſi Fa, et

bic rectam Pa in k.

OP. XXII. Ducatur per punctum

a quæ dirigatur in plagam curvæ

occurrat curvæ in punctis a et

em punctum recta quævis curvam

tis D, E, F, quæque rectis curvam

gentibus occurrat in k et m, atque

aſymptoto

aſymptoto cruris infiniti in *l*; & ſi puncta D, E, *k*, *m*, *l*, ſint ad eaſdem partes puncti P, punctum vero F ad contrarias, erit $\frac{1}{Pl} = \frac{1}{PD} + \frac{1}{PE} - \frac{1}{PF} - \frac{1}{Pk} - \frac{1}{Pm}$, ubi termini cujuſvis ſignum eſt mutandum quoties ſegmentum ad oppoſitas partes puncti P protenditur.

Sequitur ex Theor. J. Art. 9. eſt enim per hoc theorema $\frac{1}{Pk} + \frac{1}{Pl} + \frac{1}{Pm} = \frac{1}{PD} + \frac{1}{PE} - \frac{1}{PF}$.

§ 105. *Corol.* 1, Si recta PD ducatur per concurſum tangentium *ak* et *cm*; & ſumatur PM æqualis medio harmonico inter rectas PD, PE, PF, ſecundum Art. 28. erit $\frac{1}{Pl} = \frac{3}{PM} - \frac{2}{Pk}$, adeoque $\frac{1}{3}$PM erit medium harmonicum inter *Pl* et $\frac{1}{4}$P*k*. Quod ſi tangentes *ak* et *cm* concurrant in ipſo puncto M, aſymptotos quoque per M tranſibit.

§ 106. *Corol.* 2. In caſu Prop. XIX. ubi tres contactus ſunt in eadem recta linea & tres tangentes parallelæ, ſumatur punctum P ut in Propoſitione XIX. ſitque *aPc* aſymptoto parallela, occurrant *ak* et *cm* tangentes rectæ PD in *k* et *m*, eritque $\frac{1}{Pl} = \frac{1}{Pk} + \frac{1}{Pm}$, ſive *Pl* æqualis dimidio medii harmonici inter P*k* et P*m*. Quod ſi tangentes *ak* et *cm* concurrant in eodem puncto rectæ PD, erit Pl = $\frac{1}{2}$P*k*; quoniam vero in Prop. XIX. $\frac{1}{Pf} = \frac{1}{Pd} + \frac{1}{Pe}$, erit P*a* = P*c*. Fig. 47.

§ 108.

Fig. 49. § 107. *Corol.* 3. Idem dicendum eſt de caſu Prop. XX, ubi tres contactus D, E, F, ſunt in eadem rectâ quæ tranſit per P centrum gravitatis trianguli VTZ tangentibus contenti. Si autem altera rectarum curvam in *a* vel *c* contingentium (poſita *aPc* aſymptoto parallelâ) ſit rectæ DP parallela, abibit aſymptotos in infinitum, eritque crus parabolicum.

§ 108. *Corol.* 4. Iiſdem poſitis ac in Prop. XXI. Sit *cPa* aſymptoto parallela, occurrant tangentes *ak*, *cm*, rectæ VF in *k* et *m*, eritque $\frac{1}{Pl} = \frac{1}{Pk} + \frac{1}{Pm}$. Unde ſi curva diametrum habet, cum hæc neceſſario tranſeat
Fig. 52. per punctum duplex V, per punctum curvæ F ubi biſecatur tangens TFZ, ſumatur ab F verſus V, $FP = \frac{1}{4}FV$, ducatur *cPa* aſymptoto parallela, & tangens *ak* quæ diametro occurrat in *k*, & ex altera parte puncti P ſumatur, ſuper rectam PV, $Pl = \frac{1}{2}Pk$, & recta per *l* ducta ordinatim applicatis parallela erit aſymptotos curvæ. Si vero tangens *ak* ſit diametro parallela, erit crus curvæ generis parabolici. Propoſitio *Newtoni* de ſegmentis rectæ cujuſvis tribus aſymptotis & curva terminatis facile ſequitur ex Art. 4. ut ab aliis olim oſtenſum eſt.

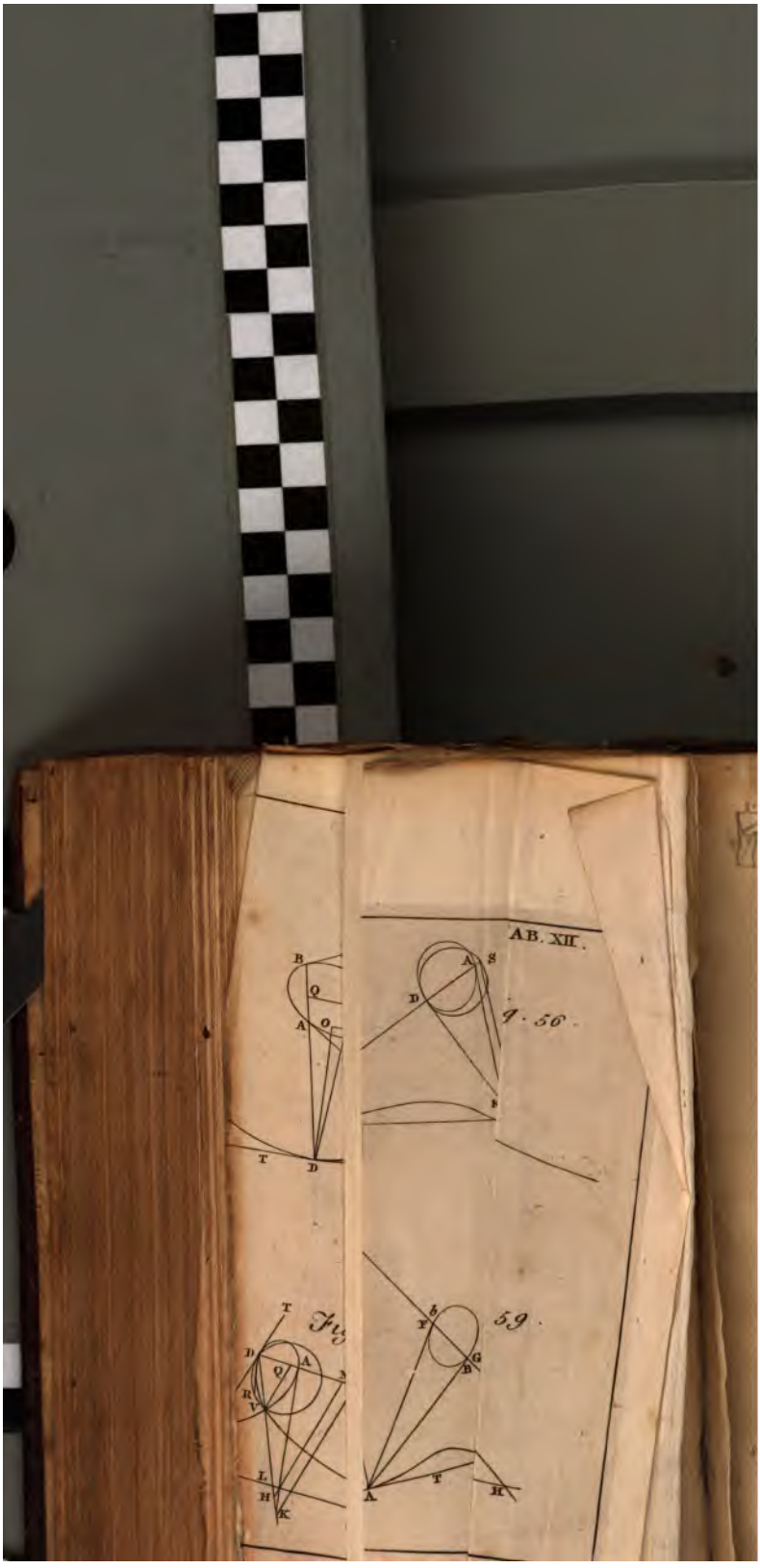
Fig. 53. § 109. PROP. XXIII. Ex puncto quovis D lineæ tertii ordinis ducantur duæ quævis rectæ DEI, DAB, quæ curvæ occurrant in punctis, E, I, et A, B; ducantur tangentes AK, BL, quæ rectæ DE occurrant in K et L. Sit DG medium harmonicum inter ſegmenta DE, DI, ad curvam terminata, atque DH medium harmonicum inter ſegmenta DK, DL, ejuſdem rectæ tangentibus abſciſſa. Sit DV medium geometricum inter

DG

7. *Corol. 3. Idem dicendum eſt de recta hp,*
s conſtitua D, E, F, ſint in eadem recta
per P centrum gravitatis trianguli VTZ
ntenti. Si autem alterus rectarum curva
axiangentium ⟨poſita ad⟩ aſymptoto prima
)P parallela, abibit aſymptotos in infinitum, e
s parabolicum.

. *Corol. 4. Iiſdem poſitis ac in Prop. III.*
ptoto parallela, occurrant tangentes a
I in k et m, eritque $\frac{1}{Pl}=\frac{1}{Pk}+\frac{1}{Pm}$. Cui
metrum habet, cum hæc tertiæ tra
um duplex V, per punctum curvæ I
gentes TFZ, ſumatur ab F verſus V, P
a aſymptoto parallela, & tangens aliqua
urrat in k, & ex alterna parte puncti I
rectam PV, $Pl=\frac{1}{2}Pk$, & recta per
pplicatis parallela erit aſymptotos curv
as ad ſit diametro parallela, erit cur
rabolici. Propoſitio Newtoni de figur
vis tribus aſymptotis & curva terminata
Art. 4. ut ab aliis olim oſtenſum eſt

Prop. XXIII. Ex puncto quo
ordinis ducantur duæ quæ
quæ curvæ occurrant in punctis E,
antur tangentes AK, BL, quæ
nt in K et L. Sit DG medium
ter ſegmenta DE, DI, ad curvam
e DH medium harmonicum
K, DL, ejuſdem rectæ tangentib
t DV medium geometricum


AB. XII.
9. 58.
59.

DG et DH, ducatur VQ parallela tangenti DT, quæ occurrat rectæ DA in Q; & ſi circulus ejuſdem curvaturæ cum linea tertii ordinis propoſitâ in puncto D occurrat rectæ DE in R, erunt HG, QV et 2DR continue proportionales.

Nam per Theor. II. (Art. 15.) eſt $\frac{QV^2}{DV^2 \times DR} = \frac{1}{DE} + \frac{1}{DI} - \frac{1}{DK} - \frac{1}{DL} = \frac{2}{DG} - \frac{2}{DH} = \frac{2DH - 2DG}{DG \times DH} = \frac{2HG}{DV^2}$ (quoniam $DV^2 = DG \times DH$;) unde $QV^2 = 2HG \times DR$, adeoque HG ad QV ut QV ad 2DR.

§ 110. *Corol.* 1. Sumatur igitur Dr in recta DE tertia proportionalis rectis HG et $\frac{1}{2}$QV, & perpendicularis rectæ DE ad punctum *r* ſecabit normalem tangenti DT ad punctum D in centro circuli oſculatorii ſive circuli ejuſdem curvaturæ cum linea propoſita, in puncto O. Si puncta E, I, K, L, ſint ad eaſdem partes ejuſdem puncti prout DH major eſt vel minor quam DG, i. e. prout medium harmonicum inter ſegmenta DK, DL tangentibus abſciſſa majus eſt vel minus medio harmonico inter ſegmenta DE, DI, ad curvam terminata.

§ 111. *Corol.* 2. Si angulus EDT biſecetur recta DA, erit QV = DV, et $2HG \times DR = DV^2 = DG \times DH$, adeoque HG ad DG ut DH ad 2DR.

§ 112. *Corol.* 3. Revolvatur recta DA circa polum D, manente rectâ DE, et HG, differentia mediorum harmonicorum DH et DG, augebitur vel minuetur, in duplicata ratione rectæ VQ. Quippe ob datam chordam circuli oſculatorii DR, manet quantitas $\frac{QV^2}{HG}$ quæ æqualis eſt 2DR.

§ 113.

TAB. XII.







Fig. 56.




Fig. 59.

atque VH : HN :: VQ : DR. Si recta DA biſecet angulum TDV, erit DR : DV :: DH : 2VH.

§ 117. PROP. XXIV. Sit D punctum quodvis lineæ tertii ordinis, occurrat tangens ad D curvæ in I, ſitque DS diameter circuli oſculatorii, quæ curvæ occurrat in A et B; unde rectæ ductæ curvam contingentes ſecent DI in K et L; ſit DH medium harmonicum inter DK et DL, & ſumatur DV ad DI ut DH ad differentiam rectarum 2DI et DH; eritque variatio curvaturæ inverſe et rectangulum SD × DV; & junctâ VS, variatio radii curvaturæ ut tangens anguli DVS. Fig. 56.

Nam per Theor. III. (Art. 17.) variatio curvaturæ eſt ut $\frac{1}{DS} \times \overline{\frac{1}{DK} + \frac{1}{DL} - \frac{1}{DI}} = \frac{1}{DS} \times \overline{\frac{2}{DH} - \frac{1}{DI}} = \frac{1}{DS} \times \frac{2DI - DH}{DH \times DI} = \frac{1}{DS \times DV}$. Variatio autem radii oſculatorii eſt ut $\frac{DS}{DV}$, adeoque ut tangens anguli DVS, per Art. 18. parabola autem quæ eandem habebit curvaturam & eandem variationem curvaturæ cum linea propoſita, determinatur ut in Art. 19.

§ 118. *Corol.* Si tangens BL ſit tangenti ad D parallela, erit DV ad DI ut DK ad IK; & ſi utraque tangentium AK, BL, fiat paraflela ipſi DΓ, erit DV = DI, adeoque variatio curvaturæ inverſe ut DS × DI. Quod ſi in hoc caſu ſit DΓ parallela aſymptoto curvæ, evaneſcet variatio curvaturæ. Quemadmodum igitur evaneſcet variatio curvaturæ in verticibus axium ſectionum conicarum; ea ſimiliter evaneſcit in verticibus diame- Fig. 57. Fig. 58.

diametrorum linearum tertii ordinis quæ ad rectos angulos ordinatim applicatas biſecant.

Fig. 59. *Schol.* Sunt autem alia plurima theoremata de tangentibus & curvatura linearum tertii ordinis. Sint, *ex. gr.* F et G duo puncta lineæ tertii ordinis unde tangentes ductæ concurrunt in curva in A. Producatur FG donec curvæ occurrat in H. Sit TAC tangens ad punctum A, & conſtituatur angulus FAN = GAT ad contrarias partes rectarum FA, GA, ſecetque AN rectam FG in N. Et ſi circuli oſculatorii occurrunt rectæ FG in B et *b*, erit GB ad F*b* ut rectangulum NFH ad NGH. Sit enim puncta *a* ipſi A quamproximum, & puncta *f*, *g*, *b*, ipſis F, G, H, quamproxima, eritque AF*a* : FG*f* : : GF : FB. FG*f* (=HG*b*) : HF*b* : : FH : GH. HF*b* (= GF*g*) : AG*a* : : *b*G : GF ; unde AF*a* : AG*a* ; : FH × *b*G : FB × GH : : GN : FN ; unde FB : G*b* : : NFH : NGH. *Sed de his ſatis.*

FINIS.